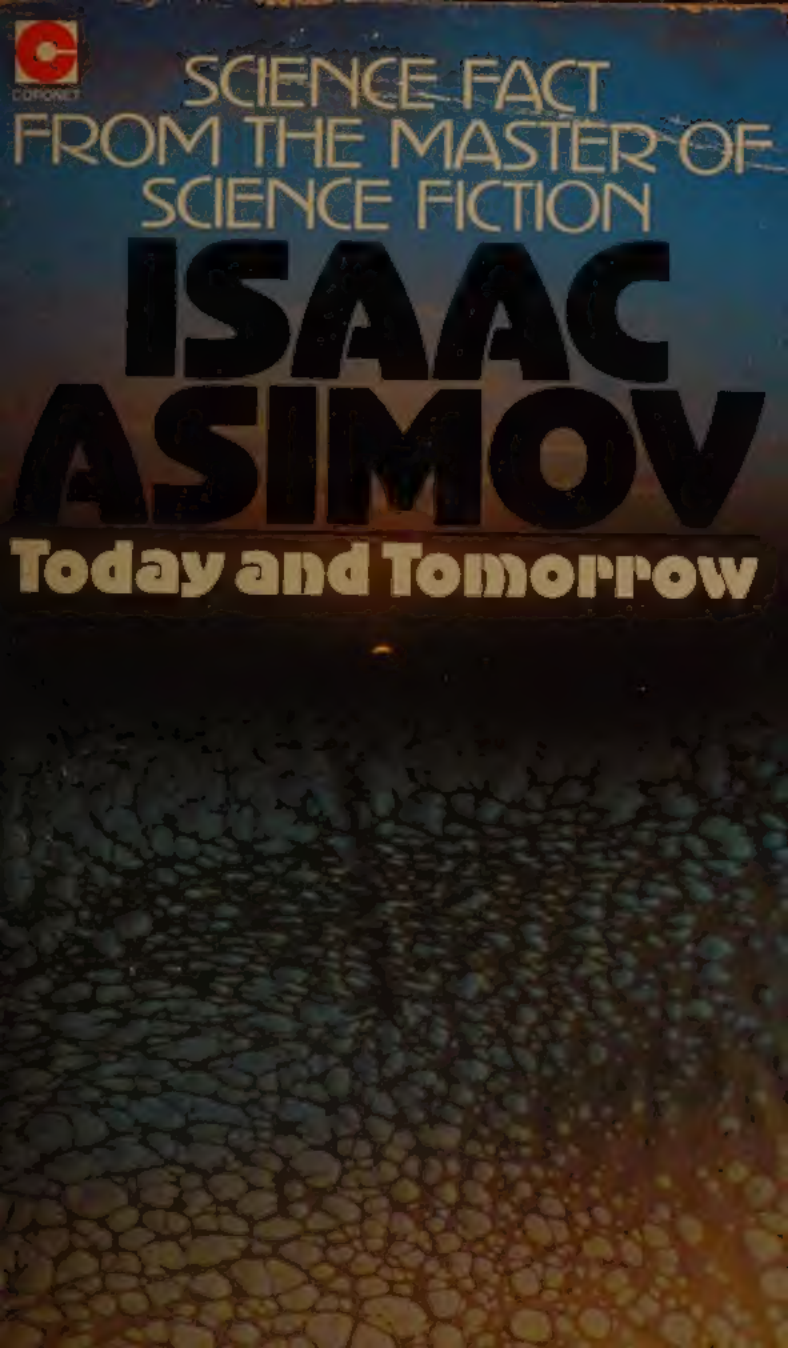
CORONET
SCIENCE FACT
FROM THE MASTER OF
SCIENCE FICTION
ISAAC
ASIMOV
Today and Tomorrow

TODAY AND TOMORROW

Some have speculated that even now Earth is being struck by two 'city-busters' per century, on the average. In 1908, for instance, an apparent meteorite struck central Siberia with enough force to gouge out craters up to 150 feet in diameter and to knock down trees for twenty miles around. Amazingly, it hit one of the few places on land where it could do its damage and not kill a single human being.

The most agonizing point is that as things stand now, there is no warning possible. A flying boulder might be aimed right at Earth at this moment, with a dead strike on Moscow, Peking, London, or New York, within the hour and, barring a chance sighting of reflected light from the Sun as it approaches the atmosphere, we wouldn't know. Not until time zero.

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TO *Michele Tempesta*
the small package
good things come in

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Introduction

I suppose it is almost inevitable that there will be some who will wonder why I bother to collect articles that have already appeared in various magazines. Have they not seen print? Is it just that I am anxious to milk them of every last penny I can collect from readers?

There is no point in denying that income is welcome. I make my living by my pen (my personal pen being an unposing electrical machine) and am pleased to have a book that may earn something for me.

But it goes beyond that. A specific issue of a magazine is short-lived. It struts and frets its hour upon the stage, and then is heard no more.* People have to hunt through the dusty confines of a second-hand bookstore if, for any reason, they want an old magazine.

And if they find it, and if it is an article of mine they are looking for, they will find it surrounded by other items and, in the case of some magazines, interrupted by copious advertisements.

But if I take all my articles and put them together in a book (supposing they are worth preserving, which I carelessly assume to be so in my own case) I have something which is more long-lived and which is concentrated me, without dilution or intrusion. The reader who wants and enjoys my articles is therefore bound to be pleased.

This about exhausts the reasons why I collect my monthly articles from *The Magazine of Fantasy and Science Fiction*. It does not, however, exhaust the reasons why I have prepared *this* book, which contains articles from magazines other than that one.

In *F&SF*, my articles appear exactly as I write them, except

* Hey, that's a good sentence. I'm glad I made it up.

for corrections of typos. My titles are invariably kept exactly as I make them up, too. Not so in the case of other magazines. In other magazines, where space is a problem, hasty surgery may be performed on my article to make room for an advertisement of some sort.

Furthermore, whereas in *F&SF*, the editor knows the readers know me and are willing to follow me through all my quirks and vagaries, the editors of other magazines have no such security. There is a certain mistrust of my articles by those other editors, a suspicion that the reader will not read it unless grabbed by the throat and made to

Consequently, an editor sometimes searches through the article for the single most dramatic sentence and starts with that, making whatever other changes are required to hide the dislocation (and calling on me to do it in detail).

There is also the matter of style. I tend to be informal, chatty, colloquial. Partly it is a matter of taste; partly it is a mistrust of the literary. This tends to make editors nervous. If I quote from Shakespeare's *Macbeth* without acknowledgment and then insert a footnote in which I actually seem to take credit for it (as I did earlier in this introduction), they will surely cut out the "Hey" as too colloquial and very probably cut out the entire footnote, afraid that the reader will not get the joke.

Finally, there is the matter of the title. I sometimes tend to the realistic. If my article is written shortly before the first landing on the Moon and deals with this lunar landing, I call it, in all honesty, "The Lunar Landing." The editor, seeking punch, changes that to "The Moon Could Answer the Riddle of Life"—which lures the reader on to read the article. But since it causes him to wade through a mess of stuff on the lunar landing before he gets to the short bit I devote to the matter of the riddle of life, he is apt to feel cheated.

Or sometimes I decide to be dramatic. If I discuss the possibility of speeds greater than that of light, I entitle the article "Beyond the Ultimate," giving it a fine flavor of paradox. The editor, however, fearing that the reader will not get the meaning

and will therefore not look at the article entitles it "Speed Limit, 186,300 M.P.S." which lacks drama altogether.

Don't get me wrong, now. I understand and sympathize with the difficulties of editors. I understand that they can't make space where there isn't any. I understand that they must catch the attention of a heterogeneous mass of readers. Therefore I very rarely quibble. I make the changes they ask of me. I cut, I slash, I alter. And I never complain about the titles they choose to put upon the articles.

In fact, sometimes they actually improve on me. I'll admit that, too.

I wrote an article on my reasons for believing there should be women astronauts. I entitled it, prosaically, 'Ladies in Space." The editor changed that title to "No Space for Women?" and, in my opinion, improved it out of all recognition.

Sometimes, too, I am caught in errors. In preparing my essay "The Flying Mountains" I read my references as saying that Mare Imbrium had been formed 700 million years ago. I therefore said so in the article, building a chain of argument upon it. At the last minute, the cute little girl in charge of checking factual statements (they're always girls, somehow) came to my office in a panic because she read the reference as saying that Mare Imbrium had been formed 700 million years after the formation of the Moon—which means nearly 4,000 million years ago.

I was stupefied when I went over the reference and found she was right. With my ears red-hot, I quickly revised the article. What a disaster that would have been if they had not backstopped me so efficiently.

So I am grateful to one and all. Honest!

Just the same, I want my articles in this book, not only because I want them all in one readily available place with no extraneous intrusions; but because I want my own titles back on them, and my own order of exposition, and my own style - except that I insist on the right to retain improvements.

One word of warning, though. The articles have been written

at different times for different audiences. There is, therefore, some overlapping here and there. Encouraged by the Erudite Copyreader, I have removed some particularly egregious examples, but others remain. Forgive me.

ISAAC ASIMOV

PUBLISHER'S NOTE

The term 'billion' throughout this book is American, i.e. one thousand million.

1 • In Biology

WHAT DO YOU CALL A PLATYPUS?

In 1800, a stuffed animal arrived in England from the newly discovered continent of Australia.

The continent had already been the source of plants and animals never seen before but this one was ridiculous. It was nearly two feet long, and had a dense coating of hair It also had a flat rubbery bill, webbed feet, a broad flat tail, and a spur on each hind ankle that was clearly intended to secrete poison. What's more, under the tail was a single opening.

Zoologists stared at the thing in disbelief Hair like a mammal! Bill and feet like an aquatic bird! Poison spurs like a snake! A single opening in the rear as though it laid eggs!

There was an explosion of anger The thing was a hoax. Some unfunny jokester in Australia, taking advantage of the distance and strangeness of the continent had stitched together parts of widely different creatures and was intent on making fools of innocent zoologists in England

Yet the skin seemed to hang together. There were no signs of artificial joining. Was it or was it not a hoax? And if it wasn't a hoax, was it a mammal with reptilian characteristics, or a reptile with mammalian characteristics, or was it partly bird, or *what?*

The discussion went on heatedly for decades Even the name emphasized the ways in which it didn't seem like a mammal despite its hair One early name was *Platypus anatinus* which is

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SOURCE: "What Do You Call a Platypus?" appeared in *International Wildlife*, March April 1972 Copyright © 1972 by the National Wildlife Federation, Inc.

Graeco-Latin for "Flat-foot, ducklike." Unfortunately, the term, platypus, had already been applied to a type of beetle and there must be no duplications in scientific names. It therefore received another name, *Ornithorhynchus paradoxus*, which means "Bird beak, paradoxical."

Slowly, however, zoologists had to fall into line and admit that the creature was real and not a hoax, however upsetting it might be to zoological notions. For one thing, there were increasingly reliable reports from people in Australia who caught glimpses of the creature alive. The *paradoxus* was dropped and the scientific name is now *Ornithorhynchus anatinus*.

To the general public, however, it is the "duckbill platypus," or even just the duckbill, the queerest mammal (assuming it is a mammal) in the world.

When specimens were received in such condition as to make it possible to study the internal organs, it appeared that the heart was just like those of mammals and not at all like those of reptiles. The egg-forming machinery in the female, however, was not at all like those of mammals, but like those of birds or reptiles. It seemed really and truly to be an egg-layer.

It wasn't till 1884, however, that the actual eggs laid by a creature with hair were found. Such creatures included not only the platypus, but another Australian species, the spiny anteater. That was worth an excited announcement. A group of British scientists were meeting in Montreal at the time, and the egg-discoverer, W. H. Caldwell, sent them a cable to announce the finding.

It wasn't till the twentieth century that the intimate life of the duckbill came to be known. It is an aquatic animal, living in Australian fresh water at a wide variety of temperatures - from tropical streams at sea level to cold lakes at an elevation of a mile.

The duckbill is well adapted to its aquatic life, with its dense fur, its flat tail, and its webbed feet. Its bill has nothing really in common with that of the duck, however. The nostrils are differently located and the platypus bill is different in structure, rubbery rather than duckishly horny. It serves the same func-

tion as the duck's bill, however, so it has been shaped similarly by the pressures of natural selection

The water in which the duckbill lives is invariably muddy at the bottom and it is in this mud that the duckbill roots for its food supply The bill, ridged with horny plates, is used as a sieve, dredging about sensitively in the mud, filtering out the shrimps, earthworms, tadpoles and other small creatures that serve it as food.

When the time comes for the female platypus to produce young, she builds a special burrow, which she lines with grass and carefully plugs. She then lays two eggs, each about three quarters of an inch in diameter and surrounded by a translucent, horny shell.

These the mother platypus places between her tail and abdomen and curls up about them. It takes two weeks for the young to hatch out The new-born duckbills have teeth and very short bills, so that they are much less "birdlike" than the adults They feed on milk. The mother has no nipples, but milk oozes out of pore openings in the abdomen and the young lick the area and are nourished in this way As they grow, the bills become larger and the teeth fall out.

Yet despite everything zoologists learned about the duckbills, they never seemed entirely certain as to where to place them in the table of animal classification On the whole, the decision was made because of hair and milk. In all the world, only mammals have true hair and only mammals produce true milk The duckbill and spiny anteater have hair and produce milk, so they have been classified as mammals.

Just the same, they are placed in a very special position. All the mammals are divided into two subclasses. In one of these subclasses ("Prototheria" or "first-beasts") are the duckbill and five species of the spiny anteater. In the other ("Theria" or just "beasts") are all the other 4,231 known living species of mammals

But all this is the result of judging only living species of mammals. Suppose we could study extinct species as well. Would

that help us decide on the place of the platypus? Would it cause us to confirm our decision—or change it?

Fossil remnants exist of mammals and reptiles of the far past, but these remnants are almost entirely of bones and teeth. Bones and teeth give us interesting information but they can't tell us everything.

For instance, is there any way of telling, from bones and teeth alone, whether an extinct creature is a reptile or a mammal?

Well, all living reptiles have their legs splayed out so that the upper part above the knee is horizontal (assuming they have legs at all). All mammals, on the other hand, have legs that are vertical all the way down. Again, reptiles have teeth that all look more or less alike, while mammals have teeth that have different shapes, with sharp incisors in front, flat molars in back, and conical incisors and premolars in between.

As it happens, there are certain extinct creatures, to which have been given the name "therapsids," which have their leg bones vertical and their teeth differentiated just as in the case of mammals.—And yet they are considered reptiles and not mammals. Why? Because there is another bony difference to be considered.

In living mammals, the lower jaw contains a single bone; in reptiles, it is made up of a number of bones. The therapsid lower jaw is made up of seven bones and because of that those creatures are classified as reptiles. And yet in the therapsid lower jaw, the one bone making up the central portion of the lower jaw is by far the largest. The other six bones, three on each side, are crowded into the rear angle of the jaw.

There seems no question, then, that if the therapsids are reptiles they are nevertheless well along the pathway toward mammals.

But how far along the pathway are they? For instance, did they have hair? It might seem that it would be impossible to tell whether an extinct animal had hair or not just from the bones, but let's see—

Hair is an insulating device. It keeps body heat from being

lost too rapidly Reptiles keep their body temperature at about that of the outside environment They don't have to be concerned over loss of heat and hair would be of no use to them

Mammals, however, maintain their internal temperature at nearly 100° F. regardless of the outside temperature, they are "warm-blooded." This gives them the great advantage of remaining agile and active in cold weather, when the chilled reptile is sluggish But then the mammal must prevent heat loss by means of a hairy covering (Birds, which also are warm-blooded, use feathers as an insulating device.)

With that in mind, let's consider the bones In reptiles, the nostrils open into the mouth just behind the teeth. This means that reptiles can only breathe with their mouths empty. When they are biting or chewing, breathing must stop. This doesn't bother a reptile much, for it can suspend its need for oxygen for considerable periods

Mammals, however, must use oxygen in their tissues constantly, in order to keep the chemical reactions going that serve to keep their body temperature high The oxygen supply must not be cut off for more than very short intervals Consequently mammals have developed a bony palate, a roof to the mouth. When they breathe, air is led above the mouth to the throat. This means they can continue breathing while they bite and chew It is only when they are actually in the act of swallowing that the breath is cut off and this is only a matter of a couple of seconds at a time.

The later therapsid species had, as it happened, a palate If they had a palate, it seems a fair deduction that they needed an uninterrupted supply of oxygen that makes it look as though they were warm blooded. And if they were warm-blooded, then very likely they had hair, too.

The conclusion, drawn from the bones alone, would seem to be that some of the later therapsids had hair, even though, judging by their jawbones, they were still reptiles.

The thought of hairy reptiles is astonishing But that is only because the accident of evolution seems to have wiped out the intermediate forms. The only therapsids alive seem to be those

that have developed *all* the mammalian characteristics, so that we call them mammals. The only reptiles alive are those that developed *none* of the mammalian characteristics.

Those therapsids that developed some but not others, seem to be extinct.

Only the duckbill and the spiny anteater remain near the border line. They have developed the hair and the milk and the single-boned lower jaw and the four-chambered heart, but not the nipples or the ability to bring forth live young.

For all we know, some of the extinct therapsids, while still having their many-boned lower jaw (which is why we call them reptiles instead of mammals), may have developed even beyond the duckbill in other ways. Perhaps some late therapsids had nipples and brought forth living young. We can't tell from the bones alone.

If we had a complete record of the therapsids, flesh and blood, as well as teeth and bone, we might decide that the duckbill was on the therapsid side of the line and not on the mammalian side—Or are there any other pieces of evidence that can be brought into play?

An American zoologist, Giles T. MacIntyre, of Queens College, has taken up the matter of the trigeminal nerve, which leads from the jaw muscles to the brain.

In all reptiles, without exception, the trigeminal nerve passes through the skull at a point that lies between two of the bones making up the skull. In all mammals that bring forth living young, without exception, the nerve actually passes *through* a particular skull bone.

Suppose we ignore all the matter of hair and milk and eggs, and just consider the trigeminal nerve. In the duckbill, does the nerve pass through a bone, or between two bones? It has seemed in the past that the nerve passed through a bone and that put the duckbill on the mammalian side of the dividing line.

Not so, says MacIntyre. The study of the trigeminal nerve was made in adult duckbills, where the skull bones are fused together and the boundaries are hard to make out. In young

duckbills, the skull bones are more clearly separated and in them it can be seen, MacIntyre says, that the trigeminal nerve goes between two bones.

In that case, there is a new respect in which the duckbill falls on the reptilian side of the line and MacIntyre thinks it ought not to be considered a mammal, but as a surviving species of the otherwise long-extinct therapsid line.

And so, a hundred seventy years after zoologists began to puzzle out the queer mixture of characteristics that go to make up the duckbill platypus - there is still argument as to what to call it.

Is the duckbill platypus a mammal? A reptile? Or just a duckbill platypus?

THE RHYTHM OF DAY AND NIGHT

Sherlock Holmes looked at the objects placed before him and then turned his glance keenly on the photographs.

Inspector Lestrade said, "These are the clues, Holmes. He died at one fifteen P.M., struck from behind by a blunt instrument, while he was taking color photographs in the garden. He died at once. And the only person with a motive for that death has a cast-iron alibi for one fifteen P.M."

"And how do you know the victim died at one-fifteen P.M.?"

"His wristwatch was broken by one of the blows and its hands are jammed at that point."

"I see," said Holmes. "And these photographs were taken at the time of the murder?"

"The camera was found under the crumpled body. We had the pictures developed, hoping it would reveal the murderer, but as you see"—and the little inspector grimaced in disgust—"they show only the garden."

"On the contrary," said Holmes, "they show much more than that. They show that the time of death was after two P.M. The murderer, having killed his victim, undoubtedly turned the wristwatch back an hour and then smashed it. Your suspect's alibi is worthless."

Inspector Lestrade smiled. "Come, now, Mr. Holmes. You have made lucky guesses in the past but surely you can't tell time from a garden."

"It is quite simple to do so, Lestrade. This garden is an accurate clock. You will note, inspector, that the scarlet pimpernels are closed but that the hawkbits are open. That places the

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SOURCE: "The Rhythm of Day and Night" appeared in *National Wildlife* as "Hidden Rhythms That Make Nature's Clock Tick" December-January 1972. Copyright © 1971 by the National Wildlife Federation, Inc.

time quite accurately between two and three P.M. I assure you that you can rely on your flowers. Whatever the wristwatch says, the victim was alive at two P.M."

No, you needn't look through your collected tales of Sherlock Holmes. You won't find the above passage because I just made it up, but it is accurate enough. That indefatigable botanist Carl Linnaeus made a list, over two centuries ago, of the times of opening and closing of flowers. Here it is:

6 A.M. Spotted Cat's Ear opens
7 A.M. African Marigold opens
8 A.M. Mouse Ear Hawkweed opens
9 A.M. Prickly Sowthistle closes
10 A.M. Common Nipple Wort closes
11 A.M. Star of Bethlehem opens
12 N. Passion Flower opens
1 P.M. Childing Pink closes
2 P.M. Scarlet Pimpernel closes
3 P.M. Hawkbit closes
4 P.M. Small Bindweed closes
5 P.M. White Water Lily closes
6 P.M. Evening Primrose opens

It is quite possible to plant a garden in the shape of the face of a clock with appropriate flowers planted at the site of the twelve numbers, and in nineteenth-century Europe this was sometimes done. On a sunny day, by merely noting which flowers were open and which closed, the time could be told, at a glance, to within half an hour.

But how do flowers know what time it is?

Ah, if we but knew the answer, we'd know a great deal, for all living things know what time it is. We do ourselves, even in the absence of all mechanical aids, whether we realize it or not, for we live by the rhythms of nature, as do all other species.

We can't help but be aware of the rhythms. The rhythm of spring and autumn, sowing and harvest, has been life and death

to mankind for thousands of years We know the rhythm of our stomachs which tell us when it is mealtime without need for a clock.

Yet of all the rhythms in nature, surely the most pronounced and noticeable is the steady alternation of day and night Plants and animals have had to adapt to it over the eons Leaves must open to the sun if plants are to live and might as well furl or droop at night Animals benefit by rest and lowered activity at night, if they hunt or forage by day; or by day, if they prowl by night.

The daily rhythm is not entirely expressed in the crude alternation of rest and activity, but is reflected in much more subtle changes. Plant leaves rise and fall in a slow rhythm that repeats itself day after day; the rate of cell division in various microorganisms rises and falls in a twenty-four-hour rhythm; the rate of egg hatching among moths does the same as does the rate of cortical hormone secretion in rats In human beings, temperature rises and falls a degree or two in a daily cycle; as does blood pressure, hormone and enzyme activity, and many another factor.

Is this because creatures simply follow the waxing and waning of light? Is it just a matter of convenience to sleep at night or wake by day? Could they establish any other rhythm if they cared to make the effort?

If that were so, it might be that if we lived somewhere where there was neither day nor night, and in isolation, so that there was no social pressure, we could do precisely as we chose and establish whatever rhythm we wished

To test this men and women have lived for months at a time in the darkness of caves During this time, they had no idea whether it was night or day outside and, since they had no clocks, soon lost all track of time Indeed, they ate and slept rather erratically. However, they also noted their temperature, pulse, blood pressure, brain waves and sent these and other measurements to the surface, where observers kept track of them in connection with time It turned out that however confused the cave-dwellers were, their body rhythm was not. The

rhythm remained stubbornly at a period of about a day through all the stay in the cave.

Actually, in the absence of the physical guideline of day-night alternation, the rhythm was a bit longer than a day – 24¼ hours. Perhaps that makes sense. Before any organism could become a land animal it had to have ancestors who for ages lived in the tidal region between sea and land. For millions of years, two rhythms counted. In addition to the light–dark alternation, the two together making 24 hours, there was the rise and fall of the tides, which depended on the rotation of the Earth, and also on the motion of the Moon during that rotation. The latter effect lengthened the rhythm slightly so that there were two high tides and two low tides every 25 hours.

By establishing a basic rhythm of 24¼ hours, some aspects of life might be adjusted to the 24-hour cycle of light and dark, and others to the 25-hour cycle of the tides. Land organisms have gone over wholly to the light–dark cycle but in its absence, the older life in the tidal region seems to reassert itself.

Thus the leaves of plants rise and fall in a day-long rhythm to match the coming and going of the sun. This is made apparent by time-lapse photography. Seedlings grown in darkness showed no such cycle, but the potentiality was there. One exposure to light—one only—was enough to convert that potentiality into actuality. The rhythm then began, and continued even if the light were cut off again. From plant to plant the exact period of rhythm varied—anywhere from 24 to 26 hours in the absence of light—but 24 hours with the help of the regulating effect of the Sun.

A 20-hour cycle could be established if artificial light were used on a 10-hour-on and 10-hour-off cycle. The leaves would rise and fall with the light, but as soon as the light were turned off altogether, the about-24-hour-rhythm re-established itself.

This daily rhythm, even in the absence of outside hints, permeates all life and Dr. Franz Halberg of the University of Minnesota named it "circadian rhythm" from the Latin *circa dies*, meaning "about a day." The circadian rhythm is the chief component of what we might call the "biological clock."

The biological clock is not absolutely inflexible It does not start at the same moment for everybody There are "morning persons" who rise cheerfully with the lark and grow sleepy in the evening; and "night persons" who drag out of bed late in the morning, but who are lively and bright at midnight Their chemistry differs, not merely their habits The body temperature that begins to rise at dawn in the morning person, may not rise till 10 A.M. in the night person (And trouble really arises when a morning person marries a night person.)

The biological clock can be adjusted The man with the night job, who must be active all night and sleep all day, has trouble to begin with Still, if he sticks it out for a while, his rhythm alters His temperature is rising and his hormones are flooding just when the temperature of other people is falling and the hormones ebbing.

There is a limit to how far one can tamper with the biological clock, however. This is shown in experiments with rat mothers, which are actively involved with their litters during a 12-hour light period and neglect them during the 12-hour period of darkness Even if the light is kept on perpetually, the rats maintain their 24 hour circadian rhythm.

If the rhythm is made 12-hour in nature, with the lights on for 6 hours and off for 6 hours, the rats try to follow the guidance of light and dark for a while, but can't maintain that for long They fall back on the circadian rhythm, nurturing their litters in alternate light periods

If the rhythm is 16-hours, with light for 8 hours and darkness for 8 hours, that rhythm cannot be so easily fitted into the circadian period. The rat mothers grow disorganized. Their body clocks do not adjust.

Even when adjustments are possible, they seem to involve a price Suppose, for instance, you take a group of mice and allow them all to live on a schedule of 12 hours light and 12 hours darkness. This fits in with their circadian rhythm and they get along famously. But suppose that at a certain time, you allow either the light cycle or the dark cycle to continue 24 hours and then start alternating again. The circadian rhythm

continues, but now it is night when the rat's biological clock says it is day, and day when it says it is night. With time, the mouse makes the adjustment. The rhythm in blood pressure, temperature, hormone secretion all shifts and then continues normally. If you make another inversion, the mice adjust again.

Suppose, next, you take two groups of mice and allow one group to live in a steady circadian rhythm without shifts, while the second group, after doing so for a while, begin to experience shifts—one a week.

It turned out in such an experiment that the mice that experienced no shifts lived an average of 94·5 weeks, but that the mice that experienced weekly shifts lived an average of 88·6 weeks. It would seem that the effort of adjusting the biological clock was sufficiently debilitating to decrease the life-span by 6 per cent.

This is by no means a purely theoretical matter. In nature, the Earth's rotation remains steady and the alternation of day and night remains constant and beyond human interference—but only if you remain in the same spot on Earth, or only shift north and south.

If you travel east or west for long distances and quite rapidly, however, you change the time of day. If you travel to Japan by speedy jet, you might land at a time when all the Japanese were eating lunch but when your own biological clock was announcing it was time to be in bed. After all, when it is 10 P.M. in New York, it is noon in Tokyo. The jet-age traveler will have difficulty matching his activity to that of the at-home people surrounding him. If he forces himself to do so, he will be tired and inefficient; he will suffer from "jet fatigue."

But what about jet pilots who are forever switching across the time zones. Does this continual interference with their circadian rhythms affect their efficiency? Their health? Their life span eventually, perhaps? Recommendations are being made now to allow pilots rest time between flights; the length of rest being determined by the number of time zones crossed after a particular flight.

Even when the circadian rhythm is allowed to run undisturbed, a creature is not the same at different points in the rhythm. As the chemical changes pulse up and down, so does sensitivity to stimuli, whether physical or chemical. When a rat is at a point in its rhythm where it is naturally somnolent, it is dull sensed and less reactive to noise. A loud noise will affect it little. At the point in its rhythm when it is active and on the alert, its hearing is sharper and its reaction intensity more extreme. In this latter case, the same loud noise which scarcely bothered it before, may throw it into a frenzy that can lead to convulsions and death.

Similarly, a rat's sensitivity to X-ray treatment varies with the circadian rhythm, and a dose that would merely make it sick at one time will kill it at another. A dose of amphetamine that will kill 78 per cent of the test animals at one time of day will kill only 8 per cent at another.

Clearly, this has important applications to medicine. It may well be advisable to plot in considerable detail the circadian rhythm of every human being who requires medication. By applying the medication at an appropriate time by the biological clock, a smaller dose might be required and side effects might be rendered less dangerous.

What keeps the biological clock so well regulated? The alternation of light and dark is surely of prime importance; but is the clock regulated by way of the eyes alone? Rats blinded at birth maintain their circadian rhythms just as accurately as do normal rats. Could it be that the alternation of light and dark somehow influences some portion of the brain directly?

Suspicion in this respect falls upon the pineal gland, a small structure in the brain. In some reptiles the pineal gland is particularly well developed and seems to be similar in structure to the eye. It is most developed in the tuatara, the last surviving species of the reptilian order, Rhynchocephalia. This lizardlike reptile (but *not* a lizard) survives only on some small islands off New Zealand, where it is now rigorously protected. The "pineal eye," a skin-covered patch on top of its skull, is particu-

cularly prominent for about six months after birth, and is definitely sensitive to light.

The pineal gland does not "see" in the ordinary sense of the word, but it may produce some chemical in rising and falling rhythm in response to the coming and going of light, and thus may regulate the biological clock

But then how does the pineal gland work in mammals where it is no longer located just under the skin at the top of the head but is buried deep in the center of the brain? Can light somehow still stimulate it? Or is it something else?

After all, circadian rhythms, once established, continue correctly even in continuous light or in continuous darkness Is there something other than light, which has a similar rhythm?

There are speculations that cosmic rays might be the answer, or rather the radiation within the atmosphere produced by cosmic ray impingement Cosmic rays approach Earth from all directions evenly and at all times of day and night evenly but they don't quite reach us evenly They are affected by Earth's magnetic field, which is, in turn, affected by the streams of particles reaching Earth from the Sun (the "solar wind") This means that cosmic radiation tends to rise and fall in a circadian rhythm of its own Could this be the regulator where the pineal gland is far within the brain, shielded from light but not from the penetrating cosmic radiation?

There is another question, too Granted that the biological clock is regulated by something (light, cosmic rays, something else) through some organ (the pineal gland, the pituitary gland, something else)—is the biological clock itself something that can be identified? Is there some chemical reaction in the body which rises and falls in a circadian rhythm and which controls all the other rhythms of temperature, blood pressure, hormone secretion and everything else? Is there some "master reaction" which we can tab as *the* biological clock?

If so, it has not yet been found.

All we can say is that the biological clock exists and is of key importance in all organisms.—But what it is, where it is, how it is set in motion, how it is regulated—we still don't know.

2 · In Astronomy

THE SUN VANISHES

On Saturday, March 7, 1970, Americans by the millions, in happy excitement, flocked to see a sight that was once the most fearful phenomenon in Nature—for there was a time when men thought it signified the possible end of all life. So fearful was the sight that no one prior to modern times bothered to record the fact that it was also by all odds the most beautiful vision the sky could ever afford us.

The phenomenon is the eclipse of the Sun, the slow vanishing of that body from its post in the sky, the coming of night when no night should be.

Primitive (and not so primitive) men would come howling into the streets and fields in times gone by, wildly beating pans or drums, shooting arrows into the sky, doing anything that might serve to frighten the monster that seemed to be devouring the Sun. Only when the monster left and the Sun reappeared, apparently unharmed, could men relax once more.

Of course it was necessary to be ever prepared, for who could tell when an eclipse might come. A Chinese legend reports that in very ancient times, an eclipse came to the capital without warning because the royal astronomers, Hsi and Ho, preferred to be drunk rather than at work. After the emperor had gotten over his imperial fright at the unexpected event, the suddenly sober astronomers were led off to execution, and all agreed it was richly deserved.

Farther west, in ancient times, the Sun's disc was encroached upon by darkness, little by little, over a field of battle in Asia

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SOURCE: "The Sun Vanishes" appeared in *Look*, March 10, 1970.
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Minor The armies of Lydia on the west and Media on the east stopped fighting and peered at the vanishing Sun. The few minutes of eclipse night came, and when it passed, the opposing generals could do only one thing They signed a treaty of peace and went home. Lydia and Media never fought again, for they knew the anger of the gods when they saw it

As it happens, modern astronomers can calculate the date of the eclipse of the Sun that took place in Asia Minor at about the time in question. It was on May 28, 585 B.C., so that the battle which came to a premature and permanent end is the earliest earthly event in all history that can be pinned down to an exact day.

The "monster" that devours the Sun is, of course, the Moon In its pathway across the sky, the Moon occasionally moves in front of the Sun and obscures its light In doing so, it displays the effect of an extraordinary coincidence The Sun is just 400 times as wide as the Moon is, and it is also just 400 times as distant from us as the Moon is. The result is that size and distance cancel each other and both bodies appear to be almost exactly the same size in our sky.

Therefore, when the Moon moves squarely in front of the Sun, it neatly covers it From no other planet can any satellite be seen to fit so perfectly over the Sun. On Earth itself, the Moon was closer millions of years ago and seemed larger; while millions of years from now it will be farther and seem smaller.

There is no astronomical reason why distance and size should match so as to give us the chance of a perfect eclipse, just in the place and time of man's existence. It is pure chance, but a very lucky chance too, for it is the perfect fit that makes the eclipse the gorgeous spectacle it is

It seems a shame to carp, but chance might have served us even better If the Moon and Sun followed the same path across the sky, then the Moon would move in front of the Sun once each month There would be at least twelve, and sometimes thirteen, eclipses of the Sun each year.

Unfortunately, the two paths are tilted, one to the other. The

Moon usually passes the Sun sufficiently higher in the sky, or sufficiently lower, to miss it altogether as viewed from the Earth. Only when the Moon passes the Sun near the point of path-intersection is there an eclipse.

This means there can only be five eclipses of the Sun, at most, in any given year. In some years, there are only two. What's more, most of these eclipses aren't total—the Moon doesn't pass squarely in front of the Sun. We will find an actual total eclipse somewhere on Earth only once every eighteen months, on the average.

The Moon, intercepting sunlight, casts a shadow, as anything else would. Passing between the Sun and the Earth, the Moon casts that shadow upon our planet. People standing on Earth's surface and finding themselves in the Moon's shadow, experience the total eclipse and the coming of a brief period of night.

But the Moon's shadow narrows with distance and by the time it reaches Earth's surface, it is shrunken nearly to a point. The shadow, which is 2,100 miles across in the neighborhood of the Moon, is down to 150 miles across, at best, at the surface of the Earth. That means only a tiny part of the Earth can experience a total eclipse at any one time.

Suppose you were on Earth's surface someplace where the Moon was squarely over the Sun so that you were standing in a total eclipse. Someone else standing a couple of hundred miles away would see past one edge of the Moon and catch a sliver of Sun. He would be seeing only a "partial eclipse." The farther away an observer was, the farther he'd see around the edge of the Moon and the more Sun would be visible. If he were a few thousand miles away, he wouldn't see the Moon's disc cover any part of the Sun and there would be no eclipse at all for him.

What counts, then, is not just the fact that there is an eclipse, but where along the Earth's surface the Moon's narrow shadow traces out a line. This can be almost anywhere, but fortunately astronomers can calculate where that line will fall, and will travel to the ends of the earth to be at those spots where

totality will occur. (Scientists have gained much knowledge from their laborious studies of eclipses. Most spectacularly a French astronomer Pierre Janssen studying an eclipse in India in 1868 discovered a new element, helium, which was only discovered on Earth thirty years later.)

For non-travelers, the wait can be long—much longer than a lifetime, alas. A particular spot on Earth must wait 360 years (on the average) between total eclipses.

Since fully 70 per cent of the Earth's surface is ocean, and since most of its land surface is desert, mountain, or jungle; most eclipses trace their paths over trackless wastes and are seen by few. Not so the eclipse of March 7, 1970, which moved over areas where it was conveniently reached by up to sixty million Americans.

The path of totality started in the mid-Pacific, moved eastward, then veered north to cross Mexico at its narrowest point. It then moved across northern Florida, missing Tallahassee by a couple of miles, and next crossed the coastal Southeast, moving over Savannah, Charleston, and Norfolk. It was just offshore in more northerly regions, but passed across Nantucket Island, then along the length of Nova Scotia and across eastern Newfoundland.

During a period of several hours there was a total eclipse over one part or another of the path traced by the shadow. In any one place, however, the shadow came and went in the space of a few minutes. Seven minutes is about the record length for any total eclipse, but in Savannah, Georgia, for instance, this eclipse lasted only 2.9 minutes from a little before 1:23 P.M. to a little after 1:25 P.M.

While it is the time of totality that is the real period of awe and beauty, the excitement begins when the Moon's disc first encroaches upon the shining circle of the Sun. Those who intend to watch an eclipse had better be in place, then, about an hour before the time of totality.

Since ordinarily (barring clouds and other obstructions) we see the Sun as an invariably perfect circle of blazing light, there is a certain wonder in seeing a small black "bite" being taken

out of it on one side. That "bite" is the only visible portion of the Moon. It is the edge of the Moon that shows up black against the brightness of the Sun, while the rest of the Moon is invisible against the scattered blue light of the sky.

Little by little, as the Moon moves across the face of the Sun, more of its blackness grows visible and more of the Sun is covered.

There is a natural desire to watch this happen, but resist the impulse to do so without extreme caution. To look at the Sun directly for even a short period of time is to risk serious damage to the eye.

One can dim the brightness of the Sun by using smoked glass or exposed film. Brief looks at the Sun through such objects are not overly dangerous. However, it is almost impossible to resist the temptation of continuing to look and if you do that, then the protection of smoked glass is insufficient. There is a particular temptation to use crossed strips of Polaroid film from dark glasses. These so darken the Sun and seem so "modern" that the user is lulled into a feeling of security. However, the Polaroid does not block out much of the infrared radiation and that can do damage.

By all means, then, use an indirect means of viewing the Sun. That can be arranged easily enough. All you need are two pieces of cardboard. In one of the pieces punch a small hole about an eighth of an inch across. That will serve as a "pinhole camera." Let the Sun shine through that hole and place the second cardboard under it. An image of the Sun will appear on the white cardboard with a piece bitten out of it, that piece corresponding to the encroachment of the Moon's disc.

By increasing the distance of the second piece of cardboard from the first, you will make the Sun's image larger and dimmer. Keep it fairly dim and you will be able to watch the growing eclipse in full detail and comfort and without the slightest scrap of danger.

In fact, if you are at a place and at a time of the year where trees in full leaf are about, they would offer a more interesting sight than that of any artificial viewer. The interstices between

the leaves act as numerous pinhole cameras and the sunlight on the ground is made up of a series of overlapping, shifting circles, each an image of the Sun. During the progress of the eclipse, each circle is bitten off at one side. The bite grows larger and eventually there are shifting, wavering crescents on the ground. Place a piece of white cardboard there and you'll see it beautifully.

As the eclipse progresses, there comes a stage where it is the landscape, not the Sun, that you want to watch. Until the Sun is half covered, no great diminution in its light is to be noticed. After that, you will become aware of dimming. By the time that four fifths of the Sun is covered and only a thin crescent remains, we are getting light from only the edge of the Sun and it is distinctly redder than we are accustomed to.

The ruddy paleness of the fading light now seems to affect the animal world. All the voluntary noises of life come to a halt. Birds that have been singing fall mute and prepare to roost. Hens gather their chicks under their wings. Uneasy dogs cower at their master's legs. A kind of unreality hovers over a strange world.

And toward the end, the light fades so rapidly that one can almost sense the Moon's gigantic shadow swooping softly down.

Just before the point of totality there comes a sight you will not want to miss. When the crescent is down to hairline thickness, look up at the Sun through your dark film. As the Moon's surface crosses in front of the last bit of Sun, the thin line of the visible Sun breaks up. You get one last fugitive look at the disappearing Sun as it shines through the valleys between the Moon's craters and mountains. The Sun shining through those valleys produces a string of bright splinters of light. These are "Baily's beads," named after the astronomer who, in 1836, first described the phenomenon. In a few seconds, they are gone.

But when Baily's beads vanish, the moment of totality has come and that is what you were waiting for. Nothing short of totality will do. Only with the last sliver of sunlight gone, do

you really see the true beauty of an eclipse. All that has gone before is as nothing in comparison.

All around the Sun is its thin atmosphere, or "corona," stretching out for millions of miles. It is lost in the Sun's glare, even when the Sun is reduced to a thin crescent. Only when the Sun's light is utterly gone, only when the moment of totality arrives, does the corona flash out.

If the Moon were a bit smaller than it is, there would never be totality, never a corona. If the Moon were a bit larger, we would never see the whole corona at once. It is the perfect fit that makes the ultimate vision possible.

At totality, look without anything darkening your vision. The light of the corona is like the light of the full Moon and you can look at it with the bare eye.

Look, and you will see immediately around the black disc of the Moon a pinkish rim. That is the Sun's lower atmosphere. It will contain spikes and streamers in graceful arching curves. With distance from the Sun they will fade and grow more delicate until there is the pearly whiteness of the true corona stretching out unevenly from the blackness of the covered Sun to a distance of several times the Sun's diameter.

If you can look away for a moment, notice that the brighter stars have emerged from daylight hiding. (It was by studying the position of such stars during an eclipse in 1919 that astronomers were able to test Einstein's General Theory of Relativity for the first time.)

Then, too, the temperature will drop noticeably and that will be accompanied by the sudden rise of a cool wind.

But look quickly, for in a few minutes the Moon will have moved enough for the Sun to begin to emerge at the side opposite from that where its last bit had disappeared. Baily's beads will suddenly appear and with that the corona will fade.

Look away now, for the first blinding crescent edge of the Sun is about to appear. Totality is over, the light will brighten, normality will gradually return and you will be left with a sight you may never see again but which, once seen, will surely never be forgotten.

AFTERWORD

This article is especially dear to me because never in my life have I seen a total eclipse, and the editor didn't guess. (The description is accurate, just the same.)

THE FLYING MOUNTAINS

There are mountains out there, flying around loose. Out there in space, I mean. Every once in a while one of them is spotted, more or less by accident, as it skims by past Earth.

One of them was discovered in 1964 by Samuel Herrick of the University of California It is called Toro, it is perhaps three miles across, and it can come as close to the Earth as 9,300,000 miles.

That doesn't seem very close, however After all, even when it does its best, Toro never approaches Earth closer than thirty-seven times the distance of the Moon

That wouldn't bother us if it would just come that close and then leave and go about its business for a good long time It doesn't, though: its motions are locked in with those of the Earth It moves out, receding farther from the Sun than we ever are, and then moves in, coming closer to the Sun than we In doing so, it follows a complicated pattern that never allows it to get entirely away from us It moves around the Sun five times every eight times we move around the Sun because on the average it remains in the aphelion position of its orbit longer than in the perihelion position.

It is as though Earth and Moon are engaged in a close-held waltz in the center of the ballroom, while far at one end, a third person is engaged in an intricate minuet of its own, one that carefully stalks, from a distance, the waltzing couple Hans Alfven, of the University of California, calls Toro a "quasi-moon" of Earth.

Toro would pose no threat to our peace of mind if it kept to its orbit forever, shuffling through its dance without change If it did, then it would have a stable orbit which we could work

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SOURCE: "The Flying Mountains" appeared in *Intellectual Digest*, July 1972 Copyright © 1972 by Communications Research/ Machines, Inc.

out in every detail as is true of our other, larger, and much more familiar Moon, which is not "quasi" at all And if the Moon, so much huger and so much closer, doesn't bother us, why should tiny Toro?

Well, there are complications.

Among these are the other planets in the solar system Each one has a gravitational pull Considering the distance of those planets, the pull is tiny indeed, and exerts only the most trifling effect on Earth, or on the Moon, which each respond to the other's much stronger gravitational pull. The effect of these minor gravitational pulls of distant planets on the orbits of Earth and Moon can be detected by only the most delicate astronomical measurements. They are called "perturbations" and are of no practical importance.

Toro is so far from the Earth, however, that Earth's gravitational hold is small and doesn't serve to hold it in place with any efficiency at all. The pull of distant planets is then a respectable fraction of Earth's pull upon Toro. So as the distant planets pass and re-pass in a complicated pattern, what are they doing to Toro's orbit?

Alfven and his associates have computerized the orbit of Toro a couple of centuries into the past and into the future, including not only the effect of the gravitational pull of the Earth and the Moon, but also of the perturbations of Venus, Mars, Jupiter, and Saturn as well Over the period for which they made their calculations, Toro did not shift significantly out of its orbit.

But beyond that in either direction?

At some time in the past, perhaps even only a few thousand years ago, Toro may have been an independent asteroid. Then once, at some close approach to Earth, planetary perturbations were such as to shift it just enough to cause it to fall into lock step with Earth And some time in the future, another perturbation might free it again.

Then, if it someday took up an independent life again, could it happen to move into an orbit so drawn that it would intersect Earth's orbit? And if so, would the two objects happen to pass

through the intersection simultaneously, so that there would be a collision?

The chances are excessively small, of course, because space, as a whole, is a perfectly enormous target and the Earth, in comparison, is a microscopic bull's-eye. The chances are, however, not zero.

And remember, Toro is not our only close neighbor in space It is the first "lock step" neighbor we have detected (always excepting the Moon itself) but in addition there are flying mountains with independent orbits of their own, that occasionally brush by us.

This fact became known to us as long ago as 1898, when the German astronomer Gustav Witt discovered a new asteroid of a most unusual type Hundreds of asteroids had been discovered in the preceding century, but all the others, every one of them, had orbits that lay entirely between those of Mars and Jupiter Even the nearest was never closer to us than 50 million miles

Witt's asteroid, however, penetrated inside the orbit of Mars At one point, its orbit came within 13 million miles of Earth's orbit If both objects were at just the right place in their respective orbits, the separation would be only half that between Earth and our nearest planetary neighbor, Venus.

Witt named the new asteroid Eros, giving it a masculine name where all other asteroids had honored the fair sex Ever since then, asteroids with unusual orbits have been masculine in name

And ever since then, asteroids that have been found to have orbits that made it possible for them to approach Earth more closely than Venus does, have been called 'Earth-grazers." This is a most uncomfortable name indeed, for they are no tiny meteorites.

Eros is brick-shaped and is fifteen miles across its longest dimension If it ever made a head-on collision with us, both bodies moving at eighteen miles a second or so, it might be just

a pinprick for Earth but it would be an unbelievably huge catastrophe for man.

To be sure, the odds against Eros ever shifting from "Earth-grazer" to "Earth-crasher" are astronomically high. No one worries about it. Besides, Eros turned out to have its uses.

The combination of small size and close approach meant that it could be detected as a sharp point with a large shift against the background of the stars ("parallax") when simultaneously viewed from two widely separated observatories. The large parallax made it possible to determine its distance with unprecedented accuracy and from that, one could determine all other planetary distances in the solar system

Astronomers had to wait for a close approach. After all, it is only once in a long while that both bodies are in those particular portions of their orbits that allow "grazing" to take place In 1931, Eros passed within 16 million miles of us and that was close enough. Nothing closer would take place for many years.

A huge program was prepared for 1931. Fourteen observatories in nine countries took part Three thousand photographs of Eros were taken over a period of seven months, and ten years (non-computer ones) were then spent on every variety of calculation before the job was completely done.

By that time, another Earth grazer had been found, too. Albert, first detected in 1911, was three miles across and could pass (every once in a long while) as closely as 20 million miles to Earth.

Then, in the years following the great Eros project, four more Earth-grazers were detected, with orbits that could carry them considerably closer to Earth than even Eros ever managed.

The climax came with the detection of the asteroid Hermes, in 1937 It was only one mile across, but preliminary calculations of its orbit showed that when everything was exactly right, when it and the Earth were at just the right spots in their respective orbits, the separation would be only 200,000 miles! Hermes would then be closer to us than the Moon was!

To be sure, the calculations were rough and astronomers

weren't positive If they could see it again, note positions, and make additional calculations, that would be very helpful The trouble is that Hermes was seen that once in 1937 and was never seen again. All that can be said is that somewhere in space there is a flying mountain a mile across, with its orbit so poorly calculated that we can't spot it again except by accident but with a good chance that that orbit might, every once in a long while, carry it uncomfortably close to us.

In 1949, the asteroid Icarus was discovered That wasn't as bad as Hermes It never comes closer than 4 million miles to us, but it comes fascinatingly close to the Sun It approaches within 17 million miles of the Sun at each of its revolutions. This is only half the distance of Mercury, otherwise the closest object to the Sun (except for a very occasional comet) If we could place instruments on Icarus, what fascinating details concerning the Sun it could tell us.

But all these Earth-grazers put together are no real source of worry. They do not represent near and urgent dangers Toro doesn't come really close; and if some of the other 'Earth-grazers" come closer on occasion, those occasions are not at all frequent.

And yet the large bodies of the solar system *have* been hit by these flying mountains Most of these strikes took place in the youth of the solar system, to be sure, when the debris left over by its formation was still thickly distributed through space The Moon picked up thousands of sizable chunks of matter and the marks left are the craters that are still clearly visible on it Mars has similar encounter-scars, and so, undoubtedly, has Mercury.

And the Earth? How has it managed to escape?

It hasn't!

The scars, however, don't show on Earth, because Earth has something that none of the other inner worlds has: a large ocean and a rampant surge of planetary life Undoubtedly, Earth, in its early history, absorbed its share of large strikes Some of these splashed into the ocean, perhaps, and left no

marks. Others scarred the land, but those scars were slowly eroded away by wind and weather — and life.

We might comfort ourselves, then, that those bad old days have passed. The flying mountains that were close enough to be dangerous have been swept up during the first billion years of the solar system's existence, leaving their gigantic splash marks in some cases.

The Apollo 14 astronauts have, for instance, brought back some rocks from the neighborhood of Mare Imbrium which may be the remnants of the object that struck the Moon 700 million years after its formation and created that mare by smashing the Moon flat for a distance of hundreds of miles in every direction. (There is a possibility that the Imbrium body was a member of the Earth-Moon system, as Toro is today, and that its orbit was altered into a collision course.)

Such a collision on Earth would gouge out an American state or a European nation, and spread destruction over a continent. If it struck the ocean it would create a splash that would drench every plain on Earth.

But they are gone, those flying mountains; or at least most of them are and the few that are left are far enough away to be safe under any but the most unlikely concatenation of circum-stances.

Still, if planet-shaking collisions are no longer likely, city-shaking collisions may still be possible. There are always more small objects of a particular sort than large ones; and if the flying mountains are down to a dozen or so in numbers, what about "flying hills"? There may be thousands of flying hills, too small to be seen through even the best telescopes, that may be littering the spaceways.

It is not surprising, then, that there should still be strikes in quite recent times, even during Man's brief stay on this planet. Such strikes should be fewer and smaller on the whole, than those giant smash-ups that formed huge craters, dozens to hundreds of miles across. Even so, the strikes are damaging enough, at least potentially.

There is the famous Barringer Crater in Arizona, which must

have been formed not more than 50 000 years ago. Desert conditions have preserved it fairly well. It is four fifths of a mile across and looks like a small Moon crater.

There are signs of earlier and larger craters on Earth, too, partially filled with water and masked by vegetation, but still seen as circular marks on the landscape when viewed from an airplane. Chubb Crater in northern Quebec, for instance, is three miles across.

That is still child's play on a planetary scale but it is the sort of strike that can utterly destroy a large city.

Some have speculated that even now Earth is being struck by two "city-busters" per century, on the average. In 1908, for instance, an apparent meteorite struck central Siberia with enough force to gouge out craters up to 150 feet in diameter and to knock down trees for twenty miles around. Amazingly, it hit one of the few places on land where it could do its damage and not kill, as far as known, a single human being.

If it had come along five hours later, Earth would have turned enough in its orbit to allow a direct hit on St. Petersburg (now Leningrad). Surely, not a building would have been left standing; not a human being left alive.

The second city-buster of this century struck in 1947, in eastern Siberia this time, and again, in an uninhabited area.

This century has been a lucky one, but it is possible to argue that at this rate, the chances are even that in the next 30,000 years or so, some good-sized city somewhere on Earth will sustain a reasonably direct hit and be nearly or entirely wiped out. The chance is perhaps one in a thousand that this will happen before A.D. 2100. The chance of its happening within the next year is tiny—but not zero.

And if it should happen in any of several particularly critical areas, an angered or panicky government leader may assume a nuclear strike to have taken place and could press the button for retaliation before the word comes through that there was no sign of suspicious radioactivity.

The most agonizing point is that as things stand now, there is no warning possible. A flying boulder might be aimed right at

Earth at this moment, with a dead strike on Moscow, Peking, London, or New York, within the hour and, barring a chance sighting of reflected light from the Sun as it approaches the atmosphere, we wouldn't know.—Not until time zero.

And because of that there is one possible justification for the space program that may be most practical of all for Earth's teeming population, and one I have not yet seen advanced

The men in the space stations of the future, the men who work in the lunar observatories, may find themselves, among other things, the big-game hunters of space.

Without an interfering atmosphere, they will have a better chance to sight the Earth-grazers. They can watch more accurately and plot more closely the orbits of those sizable bodies, those Toros and Hermes that we can see from Earth's surface. More important, they can watch for those smaller and perhaps closer bodies we cannot see and which, through their greater numbers, are the more dangerous.

Without an interfering atmosphere, the men in space will be able to detect better than we can, and chart more efficiently, the dangers of Earth's near-space. They will note the shoals and reefs of the space-sea; they will be the new iceberg watch of the vast vacuum; they will locate every whirling rock and lump of metal of dangerous size and keep an eye on them all insofar as that is possible, seeing to it that their orbits are calculated and recalculated and that every change is carefully noted.

Then perhaps a hundred years from now, or a thousand, some space-astronomer will look up from his computer to say, "Collision orbit!"

And a counterattack, kept in waiting for this necessary moment for decades, or centuries, would be set in motion. The dangerous rock would be stalked and, at a convenient, precalculated position in space, some powerful device would be shot into its path, designed to trigger off on collision.

The rock would glow and vaporize and change from a boulder to a conglomeration of pebbles. Earth would avoid the damage and be treated instead to a set of spectacular shooting-star effects.

And, sooner or later, mankind may decide on a grimmer task. Why waste time checking on orbits? Why not clear space altogether? Anything that approaches Earth more closely than 25 million miles at any time would be suspect and marked for destruction.

Perhaps if it were distant enough to be reasonably safe, or interesting enough to have scientific value, it might be spared. Eros would be spared, certainly, if only because it would surely come under the purview of the "Landmark Preservation Commission" for its usefulness to mankind in 1931. Icarus would be preserved because its close approach to the Sun makes it a unique astronomical laboratory.

But nothing else might be spared. Every other rock that could be detected in the space between the orbits of Venus and of Mars would be relentlessly stalked. Each would be examined closely for whatever of scientific interest could be extracted from it, or, possibly, for the chance of actual capture and a safe haul to the space station, the Moon, or Earth. And when examination was done and capture proven impractical, it would be destroyed.

And if, as a result, one city is left undestroyed, one massive tidal wave is left unconsummated, one particular crater on Earth is left unformed—

Then would not all the investment in space exploration have turned out to be worthwhile for that reason alone?

THE ROMANCE OF MARS

The romance of Mars began a hundred years ago with Virginio Schiaparelli.

With Schiaparelli's description of the "*canali*" just about a century ago, came the picture of an old and sophisticated, but slowly dying civilization on our sister planet—with its great canals, its jeweled cities, its lovely princesses, its spindly scholars, its savage aggressors (which author do you read?)

In science fiction, the romance has never died. Mars is still the special planet of Ray Bradbury, and Heinlein can still make it a plausible place of alien culture.

Nor was it just science-fictional imagination at work. The romance seemed quite plausible. After all, Mars had ice caps and it had an atmosphere. Surely the ice caps meant water and the atmosphere meant oxygen and the two together meant life. The air and water might be drifting away, else why the need for the vast irrigation project of the canals, but surely those very canals meant that life survived. And, if canals, surely *intelligent* life!

At the turn of the century, H. G. Wells could, with entire justice, assume an oxygen atmosphere on Mars, and an advanced civilization that could be driven by growing need into an invasion of Earth.

But then the intelligences of Mars dimmed. Year by year, they retreated—in science, if not in science fiction. The American astronomer Percival Lowell reported he could see the canals clearly and he mapped them in detail. No other astronomer, however, could really duplicate Lowell's vision of the Martian canals. Despite occasional glimpses, more and more

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SOURCE: "The Romance of Mars" appeared as an introduction to the anthology *Mars, We Love You* by Jane Hipolito and Willis E. McNelly, Doubleday, 1971. Copyright © 1971 by Doubleday & Company, Inc.

began to view them as optical illusions and more and more raised their voices to say that the emperor's new clothes did not exist after all.

The closer the investigation of the Martian atmosphere, the thinner it proved, and the less likely it seemed to be terrestrial in character. If intelligent Martians existed at all, it began to seem more and more likely that they were living now only under extreme difficulty, if at all. Did they live in domed cities or underground? Was it not more likely they had died out millions of years ago?

Was it not most likely, in fact, that they had never existed at all?

This, of course, did not mean that life did not exist, for intelligence is only an accidental concomitant of life and perhaps not even a very useful one. On Earth, life existed and flourished ebullientlly for three billion years without anything we would call an even faint intelligence.

Then how about life-minus-intelligence on Mars? There were still the ice caps, still the atmosphere—and there was a surface that showed dark markings as well as ruddy ones. If the ruddy ones were stretches of desert, might not the dark ones be vegetation? With the change in seasons, the ice caps melted in alternation, and the dark areas spread through that hemisphere in which spring had come. And if there was vegetation, ought there not to be animal life, too?

Yet successively improved studies of Mars continued to make clearer the harshness of its environment. The vision of pseudo-trees and pseudo-rodents gave way to something less ambitious. How about lichens? Surely there could be lichens.

So biologists took lichens and other plants that flourished in the high Himalayas and Pamirs and exposed them to what they thought the Martian environment was like—and they grew. The chance of life on Mars, at least simple life, seemed to become great indeed.

Then came the crucial year of 1965 and Mariner 4 skimmed past Mars and took photographs and sent them back to Earth.

For the first time, the surface was seen better than by the best telescope.

There were no canals, but there were craters The rugged terrain resembled that of the Moon. The lack of erosion indicated that the lack of air and water was not a new situation on Mars but extended backward through geological eons. Closer studies of the Martian atmosphere showed that it was even thinner than had been thought and that the temperature was colder There was no oxygen at all in the atmosphere and hardly any water anywhere. The ice caps might be frozen carbon dioxide.

No intelligent life. No higher plants and lower animals. Perhaps not even lower plants or bacteria. Perhaps no life at all.

Perhaps Mars is another dead world like the Moon.

Yet can this be? Mars's gravity is 2.4 times that of the Moon. It does have a thin atmosphere. Surely there must be some water somewhere; even if the ice caps are solid carbon dioxide, there ought to be solid water mixed with it.

And if there is water, even in small quantities, might there not be life of some sort?

Hope dies hard and that part of Martian glamour will not give up the ghost. Though every step in the study of Mars has made the planet seem more unlikely as an abode of life, the hope will not entirely vanish.

Even as I write, Mariner 9 has just taken off for Mars and will go into orbit around it (we hope) mapping the surface as it has never been mapped before.* Its maps will not answer the question of life on Mars, but eventually, an instrument package may make a soft landing and perhaps it will provide an answer. —And if not, there is the manned landing that must someday take place.

But why bother? Of what use is life of the primitive sort that

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* *Added in proof:* Mariner 9 succeeded magnificently, showing volcanoes, canyons, and even markings that look like ancient river beds

is all that can possibly exist on Mars? Who cares about germs or viruses or bare organic remnants halfway to life but never making it?

Astronomers and biologists do!

The fact of life on another world would be the greatest and most exciting discovery in either astronomy or biology to date —no matter how simple that life might be.

All life on Earth, however various it may seem, is one. It is all related biochemically, making use of nucleic acids and proteins of the same basic sort, making use of the same vitamins, the same sets of reactions, the same scheme of metabolism. In short, the trillions of organisms on Earth make up exactly *one* ecology. And though Martian life might be so sparse in numbers and variety as to be beneath contempt from the standpoint of our own lush planet, it would form a different ecology, and the number of ecologies we could study would be exactly doubled.

The fact that life existed at all would tell us something, even if we knew not one solitary detail about that life. We can fairly make the assumption that life can exist only through molecules sufficiently complex to be capable of great versatility and flexibility of reaction; and if so we would know that the Martian environment encouraged the development of such complex molecules as soon as we knew life existed.

We know this could happen on Earth (it *did* happen) and we explain it in terms of Earth's primordial environment, but how *inevitable* was the development of life? The Martian environment will scarcely allow the development we have imagined on Earth. The temperature is so low, the radiation of the Sun so feeble, the air so thin, the water so lacking, that the chances of life-type molecules forming is only a tiny fraction of what it was on Earth.

If, nevertheless, life of any sort, however simple, formed on Mars, then the physico-chemical pressures forcing it must be so strong that we can rest assured that life exists on any planet that is even approximately Earth-type in character.

If life exists—of any sort and however simple—then the next

step is to discover its biochemical basis. The possibilities are two in number The macromolecules that make it up are either proteins and/or nucleic acids, as on Earth, or (the second possibility) they are not.

If the macromolecular basis of Martian life is fundamentally different from that of Earth, then joy must surely be unconfined Not only would we have a second ecology, but one that would be utterly new to us It is impossible to speculate on how important this may turn out to be or what new insights into life we would gain if we could find a completely new variety of it

If, on the other hand, Martian life were protein/nucleic acid in basis, there might still be a very good chance that there would be variations on the theme that would be extremely interesting. There might be alternate metabolic pathways never observed on Earth; roles played by individual atoms or atom groupings unduplicated on Earth; biochemical adaptations undreamed of on Earth.

Consider one example—

All protein molecules on Earth are built up of some twenty amino acids, of which all but one are capable of either a left-handed or right-handed orientation—one the mirror image of the other Under all conditions not involving life, the two types, labeled D and L, are equally stable and equally capable of being synthesized. If an amino acid is synthesized under conditions not involving life, half the molecules are L and half are D.

In terrestrial proteins, however, with only the most insignificant and rare exceptions, all the amino acids are L. A uniform L-ness makes it possible for amino acid chains to be built more neatly and stack more snugly, but a uniform D-ness would have done just as well.

Why, then, is terrestrial life all L? Why not all D? Or why not some life forms L and others D?

We can't be sure. Did it just happen that the first protein formed was all L? Or were L and D both formed and the L happened to win out by sheer chance? Or is there some basic asymmetry in nature that makes the L form inevitable?

Well, then, would Martian proteins be L or D? Either way it might prove something about earthly life. If it were a mixture of both, one way or another, that might prove even more fascinating.

But suppose that Martian life existed and that it was biochemically precisely like that on Earth. Does that mean that there would be no interest in it at all? That it would be a trivial discovery - just more of the same?

Not at all.

For one thing, it would indicate that perhaps our biochemical basis was the only one that could support life, at least under conditions even faintly like that of Earth. Two cases would be far better evidence for this than one is. Secondly, if Martian life were precisely like earthly life, but were much simpler (as surely it must be), it might be possible to discover something about the primitive basis of life that the complex life forms on Earth obscure.

In that case, Mars would be a laboratory in which we could observe the proto-life that once existed on Earth and even experiment with it—as on Earth we could do only with a time machine.

Indeed, even if life did not exist on Mars, but if in its soil were half-formed molecules manifestly on their way to life in earthly fashion, that might be helpful. It might indicate the nature of the path once taken on Earth and we would have a laboratory for pre-biotic chemical evolution—with possibly incalculable consequences in the way of new knowledge of direct application to earthly biology.

So there it is. The fictional romance of Mars continues, but the true romance is (albeit, as yet, problematically) in the future. It will come, along with results beyond what fiction may yet have imagined, when the first microscopic fragment of anything indubitably living, or even nearly living, is detected in the cold red soil of Mars.

KNOWLEDGE IS ANYWHERE

Charity, they say, begins at home, and the bluebird of happiness is to be found in one's own backyard. So it may be, but knowledge is indivisible and can be found anywhere.

It has no boundaries. It may be that information concerning the Moon can arise out of a careful consideration of a cliffside just outside of town—or information concerning your body out of a careful analysis of radio waves arriving from dust clouds light-years away in space.

In fact, let us hope that space science *will* enlighten our biological investigations, for living cells are infuriatingly complex. They are so complex that some scientists now fear that the techniques of physics and chemistry will be forever inadequate to penetrate their intimate workings.

Yet unless and until we tease out the details of those intimate workings, we may never truly understand such diseases as cerebral palsy or cancer; we may never be able to handle genes in such a way as to improve and elevate the human machinery; worst of all, we may never be able to comprehend the workings of the brain in either its normal or abnormal aspect.

It wouldn't be so bad if we had something simple to work with as a start. That is what we do in the case of the many problems in which physics and chemistry have been successful. Simplified situations are studied in the laboratory and from these studies general rules are evolved. With the understanding of those rules fixed clearly in the mind, more and more details can be added, until we find ourselves working with quite complicated systems.

Newton's laws of motion were based on Galileo's experiments with balls sliding down slanting grooves; they ended up sending rockets to the Moon. Dalton's atomic theory began

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SOURCE: "Knowledge Is Anywhere" was distributed to various newspapers by Publishers-Hall Syndicate, Spring 1971.

with simple experiments involving atom combinations ("molecules") made up of merely two or three atoms each, it ended up helping chemists analyze the exact structure of protein molecules made up of thousands of atoms, and put together brand new molecules that had never existed in nature before.

Put it this way—What we deal with when we look at the universe is a vast panoramic picture of enormous detail. If we try to study it directly, we are lost in complications and can make nothing of it. But suppose we find, or can construct, the artist's initial concept, the few basic lines and curves on which he built the panorama. That can give us our foundation and if we add to it, little by little, additional items here and there, we can end up understanding large sections of the picture in detail.

In biology, we can't seem to do that. We are stuck with the complexity. There seems no way we can tackle the living cell by starting with something simple. We might move down to creatures simpler than a man, even much simpler—but they only seem simpler because they have fewer cells, less intricately arranged. The cell itself, even the single cell of a tiny bacterium, is always complicated; as complicated as that of a man.

Long ago, billions of years ago, before the first modern cell developed, there must have been sub-cells in existence; forms of life far simpler than the simplest we know today. If we had those forms to work with we might have something like the "basic concept" of life to which we could add, little by little, until we finally understood the modern cell.—Unfortunately, those sub-cells are long gone. No trace remains.

Of course, we can take modern cells apart, but as soon as we do, they are no longer alive. We can study the non-living parts, but even these are enormously complicated and how to go from the parts to the whole, as far as the intimate nature of all are concerned, is as yet beyond us. We might study viruses, which are far smaller than cells, but they only do their work after they have invaded cells, and once within a cell, they are lost to our view.

But if nature will not supply us with the basic concepts of life and show us the artist's original guidelines, so to speak, then

perhaps we can construct our own. Astronomers have worked out the possible chemical structure of the ocean and the atmosphere of the Earth as it may have been billions of years ago before there was any life on our planet.

The simple atoms and molecules of the beginning, in the presence of the energy of sunlight, ought to come together to form more complicated molecules. Perhaps this can be tested in the laboratory.

Back in the middle 1950s, chemists began to try to duplicate what must once have happened on the earth. A mixture of common small molecules was exposed to energy in the form of ultraviolet light or electric sparks. After a week or so, the material was analyzed and small amounts of new and more complicated molecules were found.

The next step was to begin with a mixture of the small molecules and to add to them considerable quantities of one or more of the more complicated molecules that had been formed. After a while, still larger molecules were formed.

When the process was repeated over and over, chemists ended up with amino acids, which are the building blocks of proteins; nucleotides, the building blocks of genes; rings of atoms related to the coloring matter in plants and in blood.

In fifteen years of trying to duplicate the conditions of the early Earth, chemists haven't gotten anywhere near actual living things, but at least all the substances they form in this way point in the direction of life. The more complicated the molecules they form, the more closely connected they are with the giant molecules of living tissue.

It would look as though chemists are on the right track. They seem to be repeating the process that actually took place on the sterile Earth billions of years ago, the process that ended by filling the planet with life. If they continue long enough, will they build a picture of the basic guidelines of life and guide us to an understanding of the biological problems that seem beyond us now?

Or are the chemists kidding themselves?

Do they *really* know what the Earth was like four billion

years ago? Are they *really* duplicating the original conditions? Perhaps, knowing what they want to end with, they are unconsciously designing the conditions of the experiment in such a way as to end there. If only there were some way of checking the chemists' deductions about the conditions on the very early Earth.

Suppose we look out in space and find matter before it has formed planets. Maybe the composition of that matter can tell us something about what the Earth was like when it first came into being.

All through our Galaxy of over a hundred billion stars there are clouds of dust and gas with some sort of chemical makeup. There are reasons for thinking that these clouds consist chiefly of a few different elements such as hydrogen, oxygen, carbon, and nitrogen. The gas is so thinly spread out, however, that chemists and astronomers both guessed it would consist entirely of single atoms.

Occasionally, of course, two atoms might come together and cling. In the 1930s, astronomers were able to tell from the type of light arriving from those clouds that there were carbon-hydrogen combinations (CH) and carbon-nitrogen combinations (CN) present. But nothing further was discovered. The light radiations couldn't be analyzed in enough detail.

Since then, however, astronomers have learned to receive and analyze radio waves from space. Radio waves can be studied in far greater detail than light waves can. Every atom and every molecule puts its mark on those radio waves and can be identified by its "fingerprint" so to speak.

In 1963, radio waves from certain dust clouds were analyzed by radio astronomers of M.I.T. and were found to indicate the presence of combinations of oxygen and hydrogen atoms (OH). It would not have been detected through ordinary light waves.

Astronomers were not very surprised by these two-atom combinations but to them it seemed quite unlikely that more than two atoms would come together in one place and stick there; not with the atoms originally being so far apart.

Wrong! Beginning in late 1968 at the University of Califor-

nia, the radio wave "prints" of a number of more-than-two-atom molecules were discovered. The first was ammonia, with molecules made up of one nitrogen atom and three hydrogen atoms (NH_3). Then there was water (H_2O), and hydrogen cyanide (HCN).

In March 1969 came a real surprise Using the radio telescope at Green Bank, West Virginia, astronomers located signs of formaldehyde in the gas and dust of outer space. Formaldehyde molecules are made up of a carbon atom, two hydrogen atoms, and an oxygen atom (CH_2O). No one had expected that. Then came cyanoacetylene (C_3HN), formic acid (CH_2O_2) and methyl alcohol (CH_4O). The molecule of methyl alcohol is made up of six atoms.

Astonished astronomers found they had a new science on their hands, "astrochemistry," the chemistry of the thin matter of outer space. What's more, the molecules they were detecting might also be on the highroad to life. They were beginning to point in the same direction as that shown by the chemists working with their made-up primitive mixtures in the laboratory.

It looked as though the chemists might *not* be kidding themselves.

Did that mean that if we looked harder and in more detail we might find such important compounds as amino acids, the building blocks of proteins?

In December 1970, a team of American scientists under Cyril Ponnamperuma analyzed a meteorite which fell in Australia on September 28, 1969, and found it to contain traces of five amino acids—each one of which is common to all proteins.

There is a chance, then, that the guidelines to an understanding of life may exist after all—if we can only study those gas clouds of outer space closely enough. If they are not the guidelines themselves, they may well give us enough information to enable scientists to build those guidelines with confidence.

How can we make our studies of the gas clouds more detailed? For one thing, we have to get out from under our atmosphere, which obscures so much. We must get away from Earth's distracting radio noise.

If we could build an observatory on the Moon; or place one on a space station circling the Earth; or even just launch a telescope in orbit (two attempts to do the last have failed); we might be able to get enormously sharper and clearer pictures of the radio waves coming from those clouds.

And it is just possible that if we increase our knowledge of those distant gas clouds, we *may* end up with a cure for cancer, or an understanding of the nature of genius. (It would be like going from Galileo's timing of rolling balls, to rockets reaching the Moon.)

Knowledge, you see, is wherever we find it, and it would be foolish to inhibit the search for knowledge in any direction.

The *use* we make of knowledge is another thing. One or another particular application of new knowledge may seem useless, wasteful, or even downright harmful. People may rightly regret the building of hydrogen bombs, the collecting of bacterial toxins, the indiscriminate use of insecticides and detergents. To avoid such evils, it would be wise to agree to use our knowledge with greater care and discrimination—but it would certainly be criminally foolish to deprive ourselves of knowledge altogether, lest we *might* use it wrongly.

We may use a knife to prepare a meal or to kill a man. To avoid killing, must we abolish all knives—or cut off all the hands that might hold knives?

And what about the expense of gaining knowledge? Space exploration is expensive and there is no guarantee that it will show an immediate profit. Still, it gathers knowledge and no amount of expense in gaining knowledge is equal to the expense of not gaining it.

As short a time as two and a half years ago, not one astronomer would have dreamed his science was on the threshold of the development of an exciting field of deep-space chemistry. Amino acids in meteorites had been reported before but they were dismissed as contamination; now with the knowledge of what is going on in clouds they are taken seriously. Chemists building their way toward life chemicals in the laboratory were working in a vacuum, wondering if it all meant anything; now

radio waves from light-years away are backing them up.

Even if men were willing to give up the excitement of science, the sheer adventure of following on the track of knowledge wherever that might take us, would anyone be willing to give up the great good it will surely bring all of us – if only man can somehow gain the wisdom to match his knowledge?

3 · In Chemistry

EARTH

The tradition of modern science is usually traced back to the Greek philosopher Thales (640–546 B.C.) There were scientific thinkers before him certainly, for Babylonian mathematics and astronomy were painfully built up during a two-thousand-year period before Thales, and the Egyptians certainly built their pyramids (also two thousand years before) by some method other than the haphazard heaping of stone.

Thales, however, is the first person whom we know by name and as an individual, who advanced questions concerning the Universe which he then tried to answer by observation and reason and without calling on the gods. And one of the questions he asked was: What is the Universe made of?

It is a question any inquisitive child might ask and, then, looking about him, answer: Of a vast number of things!

But Thales went further. He ignored the massive and obvious heterogeneity of the world about him and strove to penetrate to the subtle core. His question was, in essence: Is the Universe made of some one substance of which all the different objects we see are merely variations?

If the answer is "No," then we are left with a Universe built up of numerous substances associated in even more numerous relationships. The Universe might then easily be too complex for the human mind ever to grasp and man might be curious to no purpose. It is tempting to reject the answer "No" then, if only for the sake of human dignity, unless and until it is quite clear that no other alternative exists.

SOURCE: "Earth" appeared in *Smithsonian*, April 1971. Copyright © 1971 by Smithsonian Institution.

On the other hand, if the answer is "Yes," then that would be evidence of an austere simplicity to the Universe, even though that simplicity is not at once apparent. It would make more likely the notion that the Universe is guided by certain rules of behavior, certain "laws of nature" that are simple enough to be comprehended by the human mind.

So Thales answered, "Yes."

But if there was indeed a basic substance of which the Universe is composed, what might that substance be? To Thales, living in a coastal city oriented very largely toward seafaring, that substance would have to be water.

A basic substance of the Universe was called in later-century Latin *elementum* (a word of unknown derivation) and this has become "element" to us. To Thales, then, water was the element of the Universe.

Thales' conviction in this matter was not utterly convincing to others. Water was unfixed in shape and formless compared to the solid things about us. Water might therefore represent a primitive kind of matter out of which more advanced kinds could be molded—but then air was even less fixed in shape than water was, and even more formless. Anaximenes (c. 570–c. 525 B.C.) felt air might more logically be viewed as the element of the Universe.

Heraclitus (c. 540–c. 475 B.C.) carried this line of thought to an even more logical conclusion. Still less fixed and more formless than air was fire. Moreover, if the element of the Universe existed in countless variations it must have an inborn capacity for infinite change and surely anyone watching a fire would agree that the flame was constantly in the process of changing.

The opposing views on the nature of the element of the Universe might persist forever without a decision on whether any one of them, or none, was correct. Wearying, perhaps, of the profitless conflict, Empedocles (c. 490–c. 430 B.C.) offered a compromise. He suggested that there was more than one element of the Universe. To those suggested earlier, all of which he accepted, he himself added earth, and in that way arose the doctrine of "the four elements."

Aristotle (384–322 B.C.), the great synthesizer of Greek science, accepted that doctrine and this acceptance made it official for over two thousand years to come. In his orderly fashion, Aristotle pointed out that each element had its natural place in the Universe, each occupying its own sphere about the center of the Universe (which was at the center of the Earth).

Of the four elements, earth, the most compact, was closest to the center and made up the solid sphere of the Earth itself. Surrounding the earth and covering it almost entirely was a spherical shell of water, and surrounding that was a spherical shell of air. So much was clear to the most cursory observation. Fire was more difficult. If the reasoning were followed, it should exist in a spherical shell beyond the air. And occasionally, to be sure, during storms, the shell of air would be rent and the fire beyond would then be seen momentarily in the stroke of lightning.

Each element would strive to find its place. Things of earth would fall downward; water would bubble up from below; air and fire would move upward even more eagerly.

Beyond the sphere of fire lay the heavens. These must, in Aristotle's view, be of an utterly different element because the properties of things heavenly were in such sharp contrast to the properties of things earthly. On the Earth, everything changed and decayed; in the heavens, the bodies were changeless and eternal. On the Earth, natural motions were up or down; in the heavens, the natural motions were great, endless circles. The heavens therefore were of a fifth element, which Aristotle called "ether" (from a word meaning "to glow," since the heavenly bodies all glowed).

From the hindsight of modern science, it is easy to dismiss all this as a kind of primitive guessing game. The choice of earth as an element seems particularly foolish. How could the solid matter that is neither water, air, nor fire, all be lumped together as a single element? After all, the most casual inspection showed that the properties of the earthly bodies varied radically from spot to spot. There were minerals that were transparent, others that glittered, others that were dully

opaque; there were dense rocks, hard rocks, crumbly rocks; blue rocks, yellow rocks, red rocks; metals; living things—

How, then, find in all this a single element?

But the very point of an element is that it could appear in different varieties while being basically the same. In its purest, primal form, it might not even exist anywhere. The element "earth," which ought to be put in quotation marks to distinguish it from ordinary earth, could be an ideal substance, which did not exist as such but only in the various impure varieties with which we were acquainted.

And surely all the infinite varieties of "earth" about us, did share one property in common. They were all solid.

Suppose, then, that instead of giving the elements ordinary names, they had been named by their most characteristic property. Suppose the Greeks had named three of their elements, not earth, water, and air, but "solidness," "liquidness," and "gaseousness." We would then recognize the Greeks to have classified matter into its three "states," something we still do today. As for "fire," which is not matter at all, if the Greeks had said "energy" instead, we would have marveled at their insight—yet the difference would be only semantic and not substantive.

Even Aristotle's guess as to the fifth element in the heavens is not so far wrong. The most important heavenly bodies are the stars and these are made up in part of what we now call "plasma" and in part "degenerate matter" and these might well be called fourth and fifth states of matter. Aristotle's mistake was not so much in postulating a fifth element, as in not having postulated a sixth as well.

The lay interest in the elements would seem to increase as one approached the center of the Universe. The ether might fascinate the philosopher, but it was forever beyond the grasp of the practical man. Fire could be placed before his eyes, but it could not be handled. And although air could be made contact with safely, there was very little one could do with it.

Water was still more easily handled and it could be made to

undergo interesting changes If sufficiently heated, it could be made to boil and change into vapor; if sufficiently chilled, it could freeze into ice (If the ancients wrote chemical equations, they might have written: earth + fire ⟶ water; water + fire ⟶ air.)

The element earth was clearly the most interesting indeed It was what the practical man dealt with all the time. Some varieties were valuable indeed; gold, most of all

Gold was a fascinating variety of earth It had a beautiful yellow luster, it was easily worked into charming shapes; it did not change, dull, or decay. And it was very rare.

This combination of properties made gold coveted; for it was ideal as a medium of exchange. Small quantities of the so-rare gold could represent large quantities of anything else, and the transfer of gold could therefore conveniently mark the transfer (in the opposite direction) of anything else

The fact that it was the "anything else" that represented wealth and that gold only kept track of the shifts of that wealth (like chips in a poker game) was lost on most people. To them, gold was, in itself, wealth, and the theoretical speculations concerning the elements of the Universe were of interest chiefly in so far as they might make it possible to increase the supply of gold.

Practice was, of course, ahead of theory. The first smelting of metal may have taken place about 4000 B.C., millennia before Thales began to speculate Metallurgists learned their trade by the hard and slow method of trial and error, but once they had learned, they were skillful enough. Nor was it only metal that technicians worked with; there was the making of glass, the baking of brick, the fermenting of fruit juice, and so on

What it all came down to was the ability to bring about change, usually through the agency of heat Dull rock could turn to shiny metal, and two metals (copper and tin) could be blended to form a new one (bronze) better in some respects than either parent.

There was no question, then, but that the Universe exhibited change and that this change could be directed by the techniques

worked out by man What was uncertain were the *limits* of change. Since so many changes *could* take place, were there any changes that could *not?*

It is much harder to decide what can't be done, than what can, and it is not surprising that the technicians of ancient times, with the evidence of directed change all about them, felt that gold could be manufactured. In some way, two or more relatively common substances could be put together under appropriate conditions to form gold. It would have been foolish of them, and completely against such evidence as they had, to suppose that gold could *not* somehow be formed.

Until the heyday of Greek science, however, any attempts to form gold had been directed purely by hit-and-miss and nothing had succeeded. With the elaboration of the theory of the four elements, new hope arose. Perhaps a consideration of those elements might guide the technician in the proper direction toward forming gold.

Perhaps all real substances were made up of different proportions of the four earthly elements. It might then be a matter of changing those proportions—increasing the air, decreasing the earth—to change lead into gold, for instance.

In the centuries after Aristotle, the study of methods of changing one substance into another came to be called *khymeia* in Greek. A common theory for the origin of this name is that since there were important practitioners of the science in Alexandria, Egypt (the intellectual center of the Greek world in the centuries after Aristotle), the word comes from "Khem" which was the native word for Egypt. A more likely, if less romantic, possibility is that it comes from the Greek word *khyma*, meaning to fuse or cast a metal.

The *khymeists* worked in many fields, sometimes quite productively, but it was the conversion of non-gold to gold ("transmutation," meaning "to change across") that most fascinated them. What's more, it was transmutation that most fascinated the laymen who patronized the *khymeists* and thought that through their art, instant and fantastic wealth would lie at hand. (Actually, this was not so. Had any *khymeist* succeeded

in easily forming gold from lead, or from wood, and had the knowledge of the process become widespread, then gold would merely have dropped in value to that of lead, or that of wood.)

Greek science faded during the centuries of, first, pagan Roman and, then, Christian Roman domination. It was not until the Arab conquests in Asia and Africa that the old speculations of the Greeks struck new fire. In the eighth century, brilliant Arabic scholars began to consider *khymea*. They thought of it with their definite article *al*. It became *al khymea* (the *khymea*) and in Latin spelling this became *alchemia* or, in English, "alchemy."

One of the earliest and best of the Arabic alchemists was Jabir ibn-Hayyan (c. 760–c. 815), known to Europeans in later centuries as Geber. He was a careful experimentalist. He described ammonium chloride and showed how to prepare white lead. He distilled vinegar to obtain strong acetic acid and prepared weak nitric acid.

In addition, though, he and the Arabic alchemists who followed him were inevitably interested in transmutation. They delved deeper into the matter, and took up certain Aristotelian notions in greater detail. There was enough variety in the earthy substances, for instance, to indicate that "earth" might involve more than one principle ("sub-elements," so to speak).

For instance, there were seven different metals known and they had to have something, "a metallic principle," in common. Of the seven metals, one that was unique was mercury, for it was the only liquid metal. It was perhaps the closest approach to the ideal metallic principle, containing the least admixture of the non-metallic aspects of earth that made up all the solid varieties, including the six solid metals.

In addition, since metals were smelted out of ore by the use of fire and great heat, metals had to contain a "combustible principle," too. Sulfur was, again, very unusual (if not quite unique) among minerals, in that it was capable of burning. Sulfur might then be the closest approach to the "combustible principle."

It might seem, then, that metals were composed of intimate

mixtures of mercury and sulfur, with gold representing the best and most perfect mixture. Other solid metals were a kind of imperfect gold and it remained only to find some way of adjusting the proportions, adding either mercury or sulfur in some appropriate way.

Undoubtedly, mercury, or sulfur, or both, were added to the various metals in every conceivable combination without forming gold, and the feeling arose that the proper combination would take place only in the presence of some intermediary. (In modern parlance, we would say that a "catalyst" was needed.)

Speculations of this sort dated back to the Greeks, who conceived the catalyst to be a dry material. They called it *xerion* from their word for "dry." The Arabs converted this to *al-iksir* and we to "elixir." It might also be called the "philosopher's stone"; "stone" because it was dry and hard, and "philosopher" because this was the name given to those who studied the Universe. (Other fanciful properties were granted the philosopher's stone, including that of curing all disease and prolonging human life, so that we find frequent references to "the elixir of life.")

For a thousand years, alchemists searched for the philosopher's stone. It was the case of the overgrowth of a single problem strangling a science. The glamour of creating gold and the greed for the wealth such a secret process would bring (and might, in the very unlikely case that it were really kept secret, and were used very sparingly) was too much to resist. It was as though all medical progress were sacrificed in a single-minded search for a cancer cure; or if all astronomical research were stopped except for a single-minded attempt to work out the nature of the quasars.

It was worse, for a cancer cure is conceivable and the nature of the quasars ought to be penetrable, but transmutation (if the alchemists but knew) was impossible—at least under the conditions the alchemists could use.

This meant that alchemy became the happy hunting ground for frauds and fakers, and a heartbreaking affair for those legitimate few who seriously sought the process. The great Isaac

Newton, nine centuries after Jabir, wasted untold time and effort in a futile effort to work out a method of transmutation.

With the coming of the seventeenth century (Newton's), however, a new mood of experimentalism entered science. Those investigating the Universe were increasingly reluctant to make large decisions on the basis of deduction from observation and first principles. There was rather the drive to design experiments intended specifically to guide the making of those decisions. Instead of *telling* the Universe of what it was composed, the greater humility of *asking* it seemed more and more appropriate.

An important turning point came in 1661, when the Irish chemist Robert Boyle (1627–91) published a book in which even the title marked a watershed. So foul had alchemy become under the distorting effect of its overriding problem that its very name had fallen into disrepute. So Boyle dropped the Arabic first syllable and returned closer to the original Greek (but using the Latin *ch* in place of the Greek letter we usually symbolize as *kh*.) He called his book *The Sceptical Chymist*. From that point on, alchemists became "chemists" (with the further change of the *y*) and alchemy became "chemistry."

Boyle was "sceptical" because he was no longer willing to accept, blindly, the decisions on the nature of the elements, which the Greeks had arrived at through sheer speculation. Instead, he preferred to define elements in a practical and entirely empirical manner.

A substance was an element if, in actual practice, it could not be broken up into two or more apparently simpler substances, and if, in actual practice, it could not be built up from two or more apparently simpler substances.

Since bronze could be manufactured out of the proper mixture of copper and tin, bronze was not an element. Since the mineral malachite could be broken down to yield copper and other substances, malachite was not an element. However, since copper could *not* (for all chemists could do at the time) be

broken down, or built up out of, simpler substances, copper *was* an element.

This sort of definition removed the "element" from the realm of the ideal and absolute, and made it a pragmatic term that was entirely dependent upon the state of the art. By Boyle's definition and in Boyle's time, the real substances water, air, and fire, were still elements. Only earth had ceased to be an element.

Of the simpler components of the earth that made up the solid structure of our planet, one could still maintain, with perfect justice, in Boyle's time, that the minerals quartz and lime were elements. Neither could be broken down into simpler substances, *then*. Eventually, each was, and then they ceased to be elements by Boyle's definition.

In fact, there was no reason to suppose that any substance which was considered an element might not turn out to be no element at all. Something which seemed an element because the state of the art was at one time inadequate to break it down, might be broken down at a later time in a more advanced state of the art. Boyle himself might, quite reasonably, have argued that the seven known metals were certainly elements as of 1661, but might *not* be as of 1662.

As it happens, Boyle felt exactly that. His new empirical approach to the question of the elements gave him no reason to suspect that the alchemical goal of transmutation was impossible. In 1689, he urged the British Government to repeal the law against the alchemical manufacture of gold (instituted by the government because they feared the effect on the economy of a flood of synthetic gold) since he felt the law hampered chemical research.

Through the eighteenth century, chemists discovered more and more substances which were elements by Boyle's definition. By 1803, some thirty-three of those substances which are still considered elements even today were known—but even so, the definition of elements was still empirical and provisional.

In 1803, the English chemist John Dalton (1766–1844) first

formally advanced the "atomic theory," something which was in line with the thinking of Boyle and even with that of some of the Greek philosophers over two thousand years before. All matter, Dalton held, is made up of atoms and each element is made up of atoms of a characteristic type.

If atoms are the simplest substances capable of existing, then indeed the elements are the elements forever; none can possibly be broken up into simpler substances. Furthermore, if one atom cannot be changed into an atom of another type, then one element cannot be changed into another, and if gold is an element, then transmutation is forever impossible.

Nineteenth-century chemists quickly came to accept this new view, but their belief still rested on the assumptions that atoms were the simplest substances capable of existing and that one atom could not be changed into another of a different kind. Nor was it possible to decide whether a substance consisted of only one kind of atom (and was therefore an element) except by the empirical method of trying to break it down into simpler substances, and failing. So the definition of an element still depended on the state of the art, despite the atomic theory.

In 1869, the Russian chemist Dmitri I. Mendeleev (1834–1907) devised the modern periodic table, in which the elements were arranged according to their various properties. The periodic table made such sense and was so useful (even guiding chemists to the discovery of new elements) that it was strong evidence in favor of believing that the substances thought to be elements were, indeed, actually elements. Yet even so, this was merely circumstantial evidence, heightening the probability, but not yet allowing a satisfactory definition independent of the state of the art.

In the final decade of the nineteenth century, however, came the discovery of the electron and of radioactivity. It turned out, rather to the astonishment of scientists, that the atom was not the simplest possible object after all but was a rather complex structure built up of still simpler objects.

In 1913, the English physicist Henry Gwyn-Jeffreys Moseley

(1887 1915), finally—*finally*—advanced a completely rigorous definition of an element. An element, it turned out through Moseley's researches, was any substance made up of atoms all of which contained a characteristic number of protons in their nuclei. This number of protons (the "atomic number") could be accurately determined. It was 1 for hydrogen, 8 for oxygen, 26 for iron, 79 for gold, and so on.

Now, 105 different elements are known, with atomic numbers from 1 to 105 inclusive.

And now transmutation is possible again, for there are methods whereby the number of protons in the nuclei of particular atoms can be altered. Indeed, many of the more complicated atoms spontaneously break down into atoms with different proton numbers. These are "radioactive changes" which are usually accompanied by relatively large energy releases. The nuclear bombs are examples of sizable transmutations. The Sun and other stars radiate energy as a result of unbelievably vast transmutations.

Does this mean that the alchemists "were right after all"?—Only in the sense that an ultimate goal they pursued was after all realizable, *though not by any methods available to them.*

After all, you might believe firmly that you could reach the Moon by jumping, and might spend your whole life jumping with all your might, yet not reach it. If, then, Neil Armstrong and company reached the Moon by rocket, with all the backup of modern technology involved, would that mean that you (who, after all, *did* think the Moon could be reached) "were right after all"?

From Thales to the nuclear bomb!

There *are* basic substances making up the Universe, but none Thales could have conceived of in his time.—And for all we know there are yet still more basic basics of which we do not conceive today. The pursuit of knowledge has no end—for which we can all be grateful.

AIR

It was rather clever of the Greeks to consider air to be an element. It was rather clever of them to consider it at all, for the general population, even we ourselves with all our modern sophistication, ignore it completely The tendency is to look into a container full of air and say, "This is empty; there's nothing in it."

Of all the Greek elements, only air is invisible Earth and water are all about us and can be felt as well as seen. Fire is visible, and even the ether that Aristotle thought made up the heavens can be seen in the form of the glowing Sun, Moon, planets and stars.

Only air of the five elements is used as a synonym for nothing. In Shakespeare's *The Tempest*, Prospero produces a gorgeous entertainment through magic, then lets it all vanish and says:

> These our actors,
> As I foretold you, were all spirits and
> Are melted into air, into thin air

That is, into nothingness.

Yet air is not nothing and when it is in motion, though we may still not see it, we can feel it easily enough. When the motion is great enough, we feel it all too intensely. No one who has lived through a hurricane or a tornado can deny that *something* invisible exists all about us. Yet when the wind stops, it will have "melted into air, into thin air" literally, and in its place there will remain (it would seem) nothing.

The Greek engineer Hero, who lived some time in the first

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century A.D., made a special effort to refute the common misconception in his startlingly modern-sounding book *Pneumatics*. He says:

> Vessels which seem to most men empty are not empty, as they suppose, but full of air . . composed of particles minute and light, and for the most part invisible. . . If then, we pour water into an apparently empty vessel, air will leave the vessel proportional in quantity to the water which enters it . . . Hence it must be assumed that air is matter. The air when set in motion becomes wind (for wind is nothing else but air in motion) and if, when the bottom of the vessel has been pierced and the water is entering, we place the hand over the hole, we shall feel the wind escaping from the vessel, and this is nothing but the air which is being driven out . . .

Quite right, and it couldn't be better expressed today.

Nevertheless, though air is matter and, in the Greek view, an element of the universe, it was different in important properties from all other matter. It had, after all, no form, no shape. A piece of earth, such as a rock, had a definite shape which persisted for all time if left to itself. A quantity of water had no permanent shape, but if confined would take on the shape of the container, and retain that shape indefinitely. Fire had a shape that perpetually changed, but it was a definite shape of some sort at each instant of time. Ether had the shape of the heavenly bodies. Only air had no shape at all.

In Greek mythology, the Universe originally consisted of a random mixture of elements, without shape or form. The creation of the Universe as we know it, then, was not the creation of matter out of nothing, but was the imposition of form on unformed matter already existing.

To the Greeks, the original mass of unformed and unshaped matter was "chaos"; while ordered, formed, and shaped matter was "cosmos." To many thinkers, it seemed that air, unformed and unshaped, was a remnant of the original chaos. Indeed, the

Swiss alchemist Paracelsus (1493–1541) sometimes referred to air as "chaos."

Something else that impressed the early chemists was the fact that air seemed to remain permanently air. Water did not remain permanently water—if it were heated it readily changed into something that seemed to have the properties of air. Indeed, water slowly changed into a kind of air and disappeared if it were merely allowed to remain in an open container.

Air itself, however, could not be changed into any kind of water. If water were heated and the "air" formed from it were mixed with ordinary air, then that part of the air that had once been water could be turned back to water by cooling the mixture. The air itself, the air that had always been air, remained air.

The Flemish chemist Jan Baptista van Helmont (1579–1644) took note of this about 1620. He termed those varieties of air which could be formed from water or from other substances as "vapors." For air itself, he reserved the Paracelsian term "chaos." He pronounced the word, however, in Flemish fashion and spelled it as he pronounced it—"gas."

The word did not catch on at once. For a long time vapors of all sorts were spoken of as "airs." When the term did come into general use, however, two centuries after it was invented, it was used not for air alone, but for all airlike substances. Thus we can now say that water vapor is a gas.

Van Helmont discovered that some vapors differed from air not only in their ability to be returned to liquid form, but in other properties as well—and not only from air but from each other. He discovered a heavy vapor, which he called *gas sylvestre* ("gas from wood"), because he obtained it by burning charcoal. He obtained another which he called *gas pingue* ("gas from fat") by heating organic matter.

Gas sylvestre (which we now call carbon dioxide) would put out a candle flame, which ordinary air would not. *Gas pingue* (a mixture of what we today call hydrocarbons) would burn, as air would not.

Van Helmont's different vapors went unstudied in detail by him and by others largely because of technical difficulties. The vapors were difficult to isolate, for as soon as they formed, they expanded outward, mixing with the vast quantities of air all about, and were gone.

Despite Van Helmont's observations, then, it remained easier to believe that air was a single substance (though trivial variations might be imposed upon it).

In the seventeenth century, to be sure, scientists had learned how to pump most of the air out of a closed container to form a vacuum—a container that was really empty (or almost empty) and not just air-filled. The Irish chemist Robert Boyle (1627–91), a leader in the early research into vacuums, also studied the manner in which air could be compressed and made denser. His accurate studies in this respect helped show that air consisted of tiny particles (as Hero had maintained) that were widely separated, with vacuum between, and this was an important step toward the establishment of the atomic theory.

However, whether the air were pumped out or squeezed together, it remained air—thinner or denser, but air.

As the eighteenth century opened, air gained a new kind of interest, for scientists were beginning to wonder about combustion. For the first time since Hero had experimented with steam, ingenious men were beginning to use heat to boil water and to force the expanding steam they produced to do work. Primitive steam engines were in existence by 1700 and it was clear they would work only as long as a fire was burning under the boiler. Interest in what it was that made some substances burn, and not others, therefore increased sharply.

About 1700, a German chemist, Georg Ernst Stahl (1660–1734), advanced an explanation of the process of combustion. He said that substances were capable of burning because they contained something he called "phlogiston" (from a Greek word meaning "to set on fire").

As such a substance burnt, it lost its phlogiston, and it was the rapid passage of the phlogiston out of the substance that

was visible as fire. Thus wood was rich in phlogiston, but the ash left behind after the wood had burned was naturally phlogiston-free and would therefore no longer burn

As a result of the phlogiston theory, air gained a new and important role. It was a receptacle for phlogiston. When a pile of wood burned, it was the surface pieces that burned first because they were near the air that would accept the phlogiston. The inner pieces, not near the air, would not burn. They might give off vapors and char, but because air was not available, they would lose little if any phlogiston. Indeed, the "charcoal" that was formed in this way, which was lighter than the original wood, would possess a greater concentration of phlogiston and would burn with a hotter fire than ordinary wood would.

Stahl's most important and enduring contribution was his recognition that the rusting of metals was somehow analogous to the burning of wood. Iron, for instance, was full of phlogiston according to his theory. As it rusted, phlogiston poured slowly out of it, too slowly to cause a visible flame, and the iron rust (or "calx," as metallic rusts were called at the time) that formed was utterly lacking in phlogiston.

Any decent theory, in explaining observations and systematizing facts, naturally raises new questions

It would seem, for instance, that although air readily accepted phlogiston, it would only accept so much and no more. Thus, if a piece of wood were burned in a limited supply of air —in a small, closed container, for instance—it would eventually stop burning. The air about it would have gained all the phlogiston it could hold, apparently, and might be called "phlogisticated air." The partly burned wood still had the capacity for burning, of course, and would burn vigorously if put into a fresh supply of air.

If that be the case, then, how does "phlogisticated air" differ from ordinary air? Are there any differences in properties other than the failure of the former to support combustion?

Such questions would be difficult to answer as long as chemists had no convenient method for isolating and studying

gases other than ordinary air. Fortunately, the necessary technique was developed by 1727 by the English botanist Stephen Hales (1677–1761). It occurred to him to form vapors in a closed container so that they could not mix freely with unlimited quantities of air. Instead, the vapors were led from the container through a tube under water and into a second container, which was upended with its surface below the water. The vapor bubbled up into the container, driving out the water. A glass cover could then be slipped under the open mouth of the container, which would then be upended and would be full of vapor mixed with very little air.

Hales produced several different vapors in this fashion but persisted in thinking of them all as trivial varieties of air and did not study them thoroughly. Fortunately, his younger contemporary the Scottish chemist Joseph Black (1728–99) did better in this respect.

In 1756, Black strongly heated the mineral limestone, and found that it decomposed, giving off a gas and leaving behind lime. If the lime were allowed to cool and were then exposed to the gas that had been given off, it would combine with the gas once more and form limestone again. This was the first demonstration of the manner in which a gas could take part in a chemical reaction.

Because the gas could be "fixed," that is, made to combine with and become part of a solid substance, Black called it "fixed air." (Black's "fixed air," like Van Helmont's *gas sylvestre*, is what we today call carbon dioxide.)

"Fixed air" did not support combustion. What's more, when wood burned, "fixed air" was formed. Could it be, then, that "fixed air" was actually "phlogisticated air"? Certainly it seemed possible.

Black made another observation that seemed to favor this possibility. He allowed lime to stand in fresh air in which nothing had been burned. Very slowly, the lime changed over to limestone. From this, it could be seen that ordinary air contained a small quantity of "fixed air." If "fixed air" were "phlogisticated air" this would not be surprising. One might

deduce that even the freshest air contained a little bit of phlogiston, perhaps from all the fires that had poured phlogiston into the atmosphere through all of history.

And yet if "phlogisticated air" were "fixed air," then the former could not merely be ordinary air plus phlogiston. "Fixed air" was distinctly different from ordinary air in ways other than merely not supporting combustion. It was distinctly denser, it dissolved somewhat in water, it combined with lime, and so on.

This suggested another experiment, which Black's student the Scottish chemist Daniel Rutherford (1749–1819) carried through in 1772. Suppose a candle were burned in a closed container until it would burn no more. A burning candle formed "fixed air" and also "phlogisticated air." The "fixed air" could easily be removed by being bubbled through a solution of lime. If it were also "phlogisticated air," then any gas that survived passage through the lime solution would be free of phlogiston and in it a candle could burn once more.

Rutherford carried through the experiment. He formed the "fixed air" and moved it, finding that after its removal most of the volume of the original air remained. What's more, the air that survived passage through the lime solution seemed to possess all the properties of ordinary air. It was no denser than air, would not dissolve in water, would not combine with lime, and so on. And yet *it would not support combustion.*

It was this new gas which seemed to be "phlogisticated air" and that was what Rutherford called it.

Rutherford's "phlogisticated air" fit the phlogiston theory much better than Black's "fixed air" did, but it left behind one small crack in the common notion of air as a single substance. After all, there were small quantities of "fixed air" present in air, and now it turned out that "fixed air" was not merely air plus phlogiston, but was a distinct substance altogether. It remained true, however, that "fixed air," though present, was present in very small quantities and so it was generally ignored.

An even more startling discovery was made by the English

chemist Joseph Priestley one that came about through a series of coincidental events He was a Unitarian minister, who practiced chemistry as a hobby Since he lived next door to a brewery, the fermenting grain gave him ample supplies of "fixed air" to experiment with He took note of the manner in which it dissolved in water (and indeed it was Priestley who first formed "soda water" or "seltzer"—a solution of "fixed air" in water—and gave it to the world).

In order to avoid losing vapors to water, however, he began to collect vapors by passing them through mercury rather than water In this way, he was able to collect and study, for the first time, the water-soluble vapors known today as ammonia, sulfur dioxide, and hydrogen chloride.—But this turned his attention to mercury.

When mercury is heated in air, it will form a brick-red "calx " By the phlogiston theory, mercury contained phlogiston which, under the influence of heat, escaped into the air, leaving the phlogiston-free calx behind

In 1774, Priestley put some of this mercury calx in a test tube and heated it with a lens that concentrated sunlight upon it. The calx broke down to mercury again, for the metal appeared as shining globules in the upper portion of the test tube In addition, the calx gave off a gas as it broke down and this gas seemed to be very much like air in all its properties but one

When Priestley thrust a smoldering splinter of wood into the test tube containing the new gas, that splinter burst into brilliant flame. Apparently, phlogiston tended to pour into the new gas more readily than into ordinary air. Priestley decided this was because the new gas had smaller quantities of phlogiston in it than ordinary air did. After all, had it not been formed from the mercury calx, which contained no phlogiston, and under the influence of heat, which would tend to allow any phlogiston which might be present to escape?

Because it contained so little phlogiston, perhaps none at all, the new gas accepted phlogiston with particular avidity, and a piece of wood that barely smoldered in ordinary air, would

naturally burst into flame in it. Priestley therefore called the new gas 'dephlogisticated air."

Priestley's "dephlogisticated air" did, indeed, seem to be the opposite of Rutherford's "phlogisticated air." Mice died in the latter, but were particularly active and frisky in the former. Priestley tried breathing some "dephlogisticated air" and found himself feeling "light and easy."

Yet in 1774, just as the phlogiston theory seemed to be at the height of its success, it was nevertheless about to disappear forever under the hammer blows of a French chemist, Antoine Laurent Lavoisier (1743–94).

Lavoisier recognized the importance of accurate measurement. In this he was not alone, of course. Joseph Black had made careful measurements in connection with his experiments and so had others. Lavoisier had gone about it more systematically, however, and had used quantitative experiments to test theories. It was not enough, for instance, to show that under certain conditions wood would turn to ash. The question was: From a given quantity of wood, how much ash would form?

Such questions put the phlogiston theory to a hard test almost at once. It was obvious, for instance, that when wood burned, the ash left behind weighed less than the original wood. This posed no mystery, for burning wood lost vapor and phlogiston, so naturally the ash would weigh less. How much of the loss, however, was vapor, and how much phlogiston?

There was one way of answering. The rusting of metals involved the loss of phlogiston, but not the loss of vapors. Hence, any deficiency in the weight of calx was due entirely to the loss of phlogiston.—But here came a shocker. It was easy to determine that when a metal rusted, it *gained* weight. A calx was invariably heavier than the original metal from which it formed. The loss of phlogiston alone seemed invariably to result in a gain of weight.

From this, many phlogistonists concluded that phlogiston had negative weight. Since nothing else was known to have this peculiar property, the conclusion was an uncomfortable one.

Lavoisier decided to test the matter in a new way. He heated metals such as tin and lead in closed containers, with a limited supply of air. Both metals formed a calx on the surface up to a certain point and then rusted no farther. But Lavoisier did something else. He carefully weighed the container to begin with and he then carefully weighed the container after the calx had formed. *There was no change in weight.*

Since it was well known that the calxes were heavier than the metals from which they formed, that gain in weight must have been balanced by an exactly equivalent loss of weight in something else within the container. The only other substance within the container was air. Could it be then that the calx had formed not because the metal had lost phlogiston to the air, but *because it had gained something from the air?* If so, there should be less air in the container now than before it had been heated, and the container should hold a partial vacuum.

To test this, Lavoisier opened the stopcock to the vessel and air rushed in. There had indeed been a partial vacuum within. When Lavoisier then weighed the container, it had gained weight in the amount expected from the formation of calx.

To Lavoisier, and indeed to all chemists eventually, this was a fatal blow to the phlogiston theory. All combustion and all rusting were the result of the combination of air with the substance that burned or rusted. Phlogiston did not exist or, at any rate, all the facts about combustion could be explained without any reference to it.

Yet Lavoisier remained dissatisfied. In the course of rusting or combustion, not all the air would combine. Only about one fifth of it would, and thereafter nothing could make combustion continue farther. So casually did he accept the two-thousand-year-old Greek assumption that air was a single substance that for a time he failed to see why one fifth of it should act differently from the other four fifths.

In 1774, however, Priestley visited Paris and, in a conversation with Lavoisier, described his recent experiments with "dephlogisticated air."

In a blinding flash, apparently, Lavoisier saw the truth of the

matter. Ordinary air was one fifth Priestley's "dephlogisticated air" and four fifths Rutherford's "phlogisticated air" and only the former was involved in combustion. The difference between these two "airs" could not lie in the content of phlogiston, since Lavoisier had demonstrated to his own satisfaction that there was no necessity to assume the existence of phlogiston.

What he decided instead, was that the two "airs" were utterly different substances; different elements; and that the Greeks and everyone following them were wrong in assuming air to be a single substance. To emphasize this, Lavoisier gave the two "airs" different names. The "dephlogisticated air" he called "*oxygène*" from Greek words meaning "producer of sourness" since he was of the opinion that it was an essential constituent of acids. In this he was wrong, but the name has been kept ever since, and in English it is "oxygen."

As for Rutherford's "phlogisticated air," Lavoisier renamed it "*azote*" from Greek words meaning "no animal life" since animals died if placed in it. This name, however, did not survive. Since the substance formed a constituent part of the common mineral niter, it came to be called "nitrogen" ("producer of niter"). Yet there are nitrogen-containing organic substances which still incorporate the letters *azo* in their name in memory of Lavoisier's name.

To emphasize the fact that air was not an element, but was mainly a mixture of two elements (plus small quantities of still other elements not recognized for an additional century) Lavoisier would no longer use the term "air" for vapors. He went back to Van Helmont's "gas" as the general term for all airlike substances, and established its use among chemists.

Rutherford retains the credit for the discovery of nitrogen and Priestley for that of oxygen, but Lavoisier was greater than either. He served chemistry in many ways: through his emphasis on measurement, his devising of the modern system for naming chemicals, his declaration of the important principle of the conservation of mass, his writing of the first modern chemistry textbook, and so on.

Nevertheless, his insight into the nature of combustion was sufficient, all by itself, to place chemists on the right track in their study of the makeup of the Universe, a track from which they never deviated thereafter. It is with full justice, then, that Lavoisier is known as the "Father of Modern Chemistry."

And he accomplished the task by a close study of air, which, to most people even today, is simply nothing.

WATER

The Greeks thought of the elements (earth, air, water, and fire) as the fundamental components of the Universe, but not necessarily as independent substances. There seemed ample evidence that one could be converted to another.

The Greek philosopher Plato (427–347 B.C.) says so, specifically, in his dialog *Timaeus:* ". . . water . . . when melted and dispersed, passes into vapor and air. Air again, when inflamed, becomes fire: and again fire, when condensed and extinguished, passes once more into the form of air; and once more, air, when collected and condensed, produces cloud and mist, and from these, when still more compressed, comes flowing water, and from water comes earth and stones once more . . ."

Examples of such interconversions are known to all. If water is allowed to stand in an open vessel, it slowly disappears, and it can be argued that it has been converted to air. The reverse process seems to happen, as clearly and unmistakably, when first clouds and then rain appear from thin air. Many earthy substances, if added to water, seem to disappear, and how better to interpret that than to suppose they had turned to water? And if seawater is allowed to evaporate, a crust remains behind as though some of the water had turned to earth.

A volcanic eruption produces not only cinders, but vapors, and flame—air and fire being produced from earth. A thunderstorm can produce rain, hail, and lightning, so that water, earth, and fire are produced from air. (This old view of matter still persists among us today, by the way, whenever we speak of a bad storm as "the raging of the elements.")

But if the elements were interconvertible, was one of them more important than the rest; were three of them only varieties

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of the fundamental fourth? Or was there some still more basic substance, some super-element, of which all four elements were only varieties?

Greek philosophers could argue indefinitely over such matters but as long as they were content only to observe and reason, and never to experiment, they could come to no conclusion. The first to attempt to put the matter to an actual and elaborate test, was a Flemish alchemist, Jan Baptista van Helmont (1579–1644).

About 1620, he began by transplanting the shoot of a young willow tree into a large bucket of soil. He weighed the willow tree and the soil separately, and carefully kept the soil covered so that no materials could fall into the bucket and confuse the manner in which changes of weight took place. You see, if the growing plant did indeed obtain its substance from the soil it grew in (as seemed reasonable at first blush), it would follow that the soil ought to lose weight as the plant gained.

Naturally, Van Helmont had to water the willow; it wouldn't grow otherwise. For five years, he watered this tree with rainwater. It grew and flourished and at the end of the time, he carefully removed it from the bucket, knocked the soil from its roots, and weighed it. In five years of growing, the willow tree had added 164 pounds to its weight. The soil, on the other hand, had lost only two ounces.

Van Helmont deduced that the willow tree had obtained its substance from the water since that was all he added to the plant-soil system. It seemed proof—experimental proof—that water could turn into the earthy substance of plant tissue and Van Helmont was convinced thereby that water was the basic element and the primal substance of the Universe.

(Actually, Van Helmont made the mistake of underestimating the importance of the fact that air also touched the growing plant. We now know that a major part of the plant substance was derived from the carbon dioxide of the atmosphere. It was just about this period, too, that carbon dioxide was discovered and studied. By whom? As it happened, by Jan Baptista van Helmont.)

Van Helmont was, however, at the end of an era. Within a generation of his death, new notions of elements were rising. Beginning with the Irish chemist Robert Boyle (1627–91), the attitude developed that an element was identified not through deduction but through experiment. Something that could not be further simplified in the laboratory was an element. From that standpoint, earth was not an element but a mixture of elements (see the earlier chapter, *Earth*).

The statement that water could be turned into earth had a new kind of meaning in the new chemistry. Into which elements of earth could it be turned? And which was the simpler, and therefore *the* element, the water, or the particular earthy element into which it had turned?

Nevertheless, many chemists clung to the old views, comfortable with the sonorous opinions of the great ancients, opinions that were so complete, so final. They were naturally uneasy with the new ways that involved eternal experimentation and constant changes in point of view.

As late as 1770, when seventeen different solid materials were already recognized as so many different elements, and when different gases were on the point of being recognized as elements—some still held to the old notions and maintained, in archaic fashion, that water could be converted into earth.

They conformed, however, to this extent. They pointed to experimental evidence. It had been observed many times that if water were boiled for a long time in a glass vessel, at least some of the water hardened and coalesced into solid particles which could be seen plainly and whose presence could not be disputed.

In 1770, however, a new man was on the scene. The French chemist Antoine Laurent Lavoisier (1743–94) regarded the science with fresh and vigorous eyes. To him, experimentation had to be *quantitative;* it had to involve the exact determination of "How much?" There had been others before Lavoisier who had experimented quantitatively; Van Helmont and Boyle, to name two. It was Lavoisier, however, who went about it so systematically and demonstrated the importance of measure-

ment in chemistry so unmistakably as to make it an integral part of the science forever.

Why not, then, use measurement as an aid in the interpretation of the experiment in which water boiled itself, at least partly, into earth?

Lavoisier began with a large, clean glass vessel which he weighed carefully. He added water and heated it till the air within the vessel was driven out and replaced by steam. He then sealed the vessel and weighed it with the water content. Subtracting the weight of the empty vessel gave him the weight of the water itself

He then heated the water for over three months, during which time it boiled gently and continuously. The steam condensed at the top of the vessel and rolled down to the bottom to be boiled again. In that period of time, distinct grains of solid appeared in the flask.

After 101 days, he stopped the fire and let the vessel cool He weighed it again, with its water content, and the total weight of vessel plus water had not changed measurably. Filtering out the solid material, he found the weight of the water itself was also unchanged The weight of the empty dried glass container, however, had *decreased* by a thirtieth of an ounce.

It was clear now what had happened. Through prolonged exposure to hot water, some of the substance of the glass vessel had eroded away. The solid flecks were from the glass and not from the water, and water had not been turned into earth. This was the final defeat of the old Greek notions of the elements.

Through the decade of the 1770s, the new view of elements received further confirmation. Different gaseous elements were discovered and, in 1774, Lavoisier presented strong evidence that air was no more an element than earth was (see the earlier chapter, *Air*). Air, he maintained, was a mixture of two elements which he named oxygen and azote (though the name nitrogen is now used for the latter).

With earth and air gone from the list of elements, what about water? Was water an element in the new-fashioned meaning of

the word? Could water be broken down to simpler substance? Could it be built up from simpler substances?

This question arose at a time when many chemists, especially in England, held to the phlogiston theory, then three quarters of a century old. They felt that combustion involved the transfer of a subtle, weightless fluid, phlogiston, from one substance to another.

Ordinary air would accept phlogiston from a fuel, such as wood or oil, and would thus support combustion. When it had accepted all the phlogiston it could hold, it would take no more and would no longer support combustion. Such "phlogisticated air," as it was called, was actually prepared, and isolated in pure form. On the other hand, if air lost what little phlogiston it had under ordinary circumstances, the "dephlogisticated air" that was formed would support combustion with particular vigor. It, too, was prepared and isolated.

Lavoisier's reasoning pointed to the conclusion that "phlogisticated air" and "dephlogisticated air" were really the two different gaseous elements, nitrogen and oxygen, respectively, but the English chemists would not, for a while, accept that.

One of these stubborn English phlogistonists was the chemist Henry Cavendish (1731–1810). In 1766, he had treated certain metals with acid and had noted that a gas was given off which was extremely inflammable. He called it "inflammable air." Actually, this gas had been noted earlier by several chemists, including Boyle, but Cavendish was the first to describe it carefully and to work with it, so he is usually considered its discoverer.

Cavendish was fascinated by the unusual properties of "inflammable air." For one thing, it was extremely light, much lighter than air. Secondly, it burned so easily, even explosively.

By the phlogiston theory, combustible substances contained phlogiston. It was the loss of phlogiston to the air that was marked by flame. Suppose one could isolate phlogiston itself and transfer it to air without the interference of any accompanying inert material of wood or oil? Would not the result be a particularly ready and even explosive combustion? Might the

light, combustible "inflammable air" really be phlogiston?

When "inflammable air" burned, whether it was pure phlogiston or merely a gas with an abnormally high phlogiston content, the end product ought to be "phlogisticated air."

Some chemists had observed the burning of "inflammable air" but had come to no conclusion as to the product. For one thing, they worked with small quantities and any product formed was present only in traces. Some reports had spoken of droplets of liquid forming after "inflammable air" had burned, but there was no clear identification of that liquid.

Cavendish had tried such experiments also and received no clear-cut answers. He puzzled over the early results and held his council till he had straightened the matter out to his own satisfaction.

Finally, in 1784, he felt on sufficiently firm ground to describe what he had done. He began with a large quantity of "inflammable air" and plenty of ordinary air. When all the "inflammable air" had been burned under conditions designed to retain the product, he found about a quarter of an ounce of liquid at the bottom of the vessel. That was enough to analyze, and the results were rather startling—he had formed water.

Cavendish sought to explain this in terms of the phlogiston theory.

Suppose that water, in its normal state, possessed a certain amount of phlogiston; not enough to make water combustible, but some.

Suppose, next, that more phlogiston could somehow be pumped into it; a great deal. Possessing a great deal of phlogiston, water would have a strong tendency to lose the excess easily and that would make it combustible. Indeed, water with an abnormally high content of phlogiston would be "inflammable air."

On the other hand, suppose that in some way, water were forced to give up the phlogiston it ordinarily carried. It would then have a strong tendency to absorb phlogiston again. Things would burn in this "dephlogisticated water." Indeed, "de-

phlogisticated water" might well be identical to what was then being called "dephlogisticated air."

Instead of "inflammable air," then, let us write "water + ph" (where "ph" stands for phlogiston) and for "dephlogisticated air" let us write "water − ph." When "inflammable air" burned to form water, then what happened, according to Cavendish's speculation was:

$$(\text{water} + \text{ph}) + (\text{water} - \text{ph}) \longrightarrow \text{water}$$

Mathematically, we see that "+ph" and "−ph" cancel. Chemically, we see that the excess phlogiston in the "inflammable air" transfers to the phlogiston-deficient "dephlogisticated air," leaving water, with its moderate phlogiston content. —And, of course, water remains an element, modified only by varying phlogiston content

This sounds awfully neat but, actually, if allowed to stand, it would let loose a wilderness of confusion. If "dephlogisticated air" and "dephlogisticated water" were one and the same, then when phlogiston was added, was air or water produced? If "inflammable air" burned, it became water, certainly, but if charcoal burned, the "dephlogisticated air" absorbed all the phlogiston it could take, without forming a trace of water at any time.

Lavoisier heard of Cavendish's experiments almost at once, but he did not interpret them according to the phlogiston theory. He was quite convinced that no such thing as phlogiston existed. Air was composed of nitrogen and oxygen, and combustion consisted of the combination of the burning substance with oxygen.

He repeated Cavendish's experiment, confirmed the production of water, and interpreted this as signifying that "inflammable air" combined with oxygen to form water. He renamed "inflammable air" at once, calling it "hydrogen" from Greek words meaning "water-former" and that has been used ever since.

By Lavoisier's system, the burning of hydrogen took on a

new and much greater importance. It meant that water was not an element, but was a combination of two simpler substances, the elements hydrogen and oxygen.

To maintain that water was a compound substance and not an element was something that needed all the evidence one could gather. Having argued that hydrogen and oxygen could be combined to form water, Lavoisier next wished to demonstrate that water could be pulled apart again to form hydrogen and oxygen.

This he could do, but only in part. He passed steam through a heated gun barrel and the hot iron pulled the oxygen out of the steam. That this had happened was proved, indirectly, by the rapid development of rust along the inner surface of the barrel, for rust, by Lavoisier's chemistry, was a compound of iron and oxygen.

To be sure, the oxygen was not isolated as a gas and its formation demonstrated directly, but at the other end of the barrel, what was left of the water after the oxygen had been subtracted appeared: a stream of hydrogen.

The final nail in the coffin of water-as-an-element came in 1800, six years after Lavoisier's tragic and unjustified death on the guillotine during the French Revolution. In 1800, the Italian physicist Alessandro Volta (1745–1827) developed the first electric battery, a device which served to produce a usable current of electricity. The news reached England on March 20 and by May 2 an English chemist, William Nicholson (1753–1815), and his colleague, an English surgeon, Anthony Carlisle (1768–1840), had constructed a battery of their own.

Nicholson and Carlisle used the battery to pass a current through water and found bubbles of gas being given off. Investigation soon showed these to consist of hydrogen and oxygen and it was not at all difficult to collect them separately. Water had been "electrolyzed" and Lavoisier's contention had been proved beyond dispute.

This was scarcely needed, however. Lavoisier's work had carried conviction. Some of the older chemists went their way

stubbornly, but the new generation was Lavoisier's. When Cavendish died in 1810, he was the last of the phlogistonists.

Lavoisier's discovery of the compound nature of water (made possible by his prior discovery of the true nature of air) proved of vital importance in two ways.

Lavoisier had noticed that when chemical reactions took place in a closed system, the mass (considered a measure of the quantity of matter present) never changed, whatever the reaction. Was this universal, or did it apply only to the simple mineral substances that chemists worked with?

When coal burned, oxygen was consumed and carbon dioxide was produced. When animals (including man) breathed, oxygen was consumed and carbon dioxide was produced. Must it not be, then, reasoned Lavoisier, that respiration was a form of combustion taking place in living tissue, and was the quantity of matter maintained unchanged (that is, was matter "conserved") in the body also?

Between 1782 and 1784, Lavoisier and a co-worker, Pierre Simon de Laplace (1749–1827)—far better known in later years as a great astronomer—had carefully measured the oxygen consumed and carbon dioxide produced by a guinea pig and matched the heat developed by it with that developed by burning ordinary carbon under conditions that consumed an equal quantity of oxygen.

The results were puzzling. Some of the oxygen consumed by the guinea pig did not show up as carbon dioxide. Had some of the oxygen disappeared? What's more the guinea pig produced more heat for the oxygen it consumed than the coal did. Did living tissue produce heat out of nothing?

As soon as the compound nature of water was worked out, Lavoisier had the answer to the puzzle. It was not merely the carbon of living tissue that combined with oxygen, but the hydrogen also. It was not merely carbon dioxide that was being produced, but water, too. Once the water content of the expired breath was measured, that accounted for the missing oxygen. The greater amount of heat formed by combining hydrogen

(rather than carbon) with oxygen, explained why the guinea pig produced more heat than expected.

Lavoisier was convinced, then, that the quantity of matter remained constant even in the complicated and mysterious reactions that went on in living tissue. He announced his "law of conservation of matter" and that has been a cornerstone of experimental chemistry (despite its slight modification by Einstein's theory of relativity) ever since.

The discovery of the compound nature of water led onward, after Lavoisier's death, to something that was even more revolutionary. Lavoisier's stress on the importance of measuring had wide influence and meant that chemists were not content with noting that hydrogen and oxygen combined to form water. The question now became: How much hydrogen combined with how much oxygen to form how much water?

Cavendish reported in 1784 that a particular volume of hydrogen required two and a half times its own volume of air for complete burning. Since one fifth of the air was oxygen, this meant that a particular volume of hydrogen combined with half its own volume of oxygen.

In 1786, the French mathematician Gaspard Monge (1746–1818) reported his work in this area. He weighed the oxygen and hydrogen that combined and the water that was produced. He found, first, that the water produced had exactly the mass of the hydrogen and oxygen (together) with which he had started, thus upholding the law of conservation of matter. Second, he found that a given weight of hydrogen combined with eight times its own weight of oxygen. (The oxygen might have a smaller volume than the hydrogen it combined with, but even that smaller volume was considerably heavier than the very light hydrogen.)

Similar measurements of the relative weights of different elements that combined to form a particular compound were carried out by others, particularly by the French chemist Joseph Louis Proust (1754–1826). By 1799, Proust was able to maintain that all compounds consisted of combinations of definite

proportions of elements by weight, and that these proportions did not and could not vary. The case of hydrogen and oxygen combining in a 1-to-eight weight-ratio remained the most spectacular and easily cited case.

Proust's "law of definite proportions" gave an enormous impetus to the development of an atomic theory. Many of those who had pondered on the nature of the Universe had come to the conclusion that matter must be made up of tiny indivisible units, even back in Greek times. So far, though, it had only been a matter of speculation.

Beginning in 1803, however, the English chemist John Dalton (1766–1844) went a crucial step farther. Not only did he postulate the existence of atoms, as many before him had done, but for the first time in human history he began to work out what their properties might be, from experimental data.

Suppose both hydrogen and oxygen are made up of atoms, and that in forming water one atom of hydrogen combines with one atom of oxygen. If so, the most direct way of accounting for the 1-to-8 ratio of combination by weight is to suppose that the single oxygen atom is eight times as heavy as the single hydrogen atom. The actual weight of the two atoms could not be determined by Dalton, but he could state them in relative terms. If the weight of the hydrogen atom were set at 1, then the weight of the oxygen atom would have to be 8. He determined the weight of other types of atoms on this same basis, by using the law of definite proportions, and thus devised the first table of "atomic weights."

It was that which converted the atom from the vague speculation of the philosopher to a concept that was useful, and even indispensable, to the chemist.

To be sure, Dalton was incorrect in some details. It was not long before it was pointed out that since, in terms of volume, two parts of hydrogen combined with one part of oxygen, it followed that two atoms of hydrogen combined with one of oxygen to form water. (The terms of the argument were more complicated and convincing than the mere statement would make it seem.) In that case, the single oxygen atom was not

eight times heavier than a single hydrogen atom; it was eight times heavier than *two* hydrogen atoms and therefore sixteen times heavier than one. If the atomic weight of hydrogen is set at 1, then the atomic weight of oxygen is 16.

Despite such correction, and many others, and despite considerable elaboration and increased sophistication, Dalton's structure, stemming in large part from the manner of combination of hydrogen and oxygen, remains the framework of modern chemistry.

And what of Lavoisier?

It is often considered ironic that in Lavoisier's lifetime, important elements were discovered by lesser men, while Lavoisier himself, the greatest of all chemists in history, never discovered [redacted]

Hydrogen and oxygen bear the names that Lavoisier gave them, for instance, but the credit for their discovery goes elsewhere.

Yet Lavoisier must not be downgraded for this. In the case of air and water, he had *un*discovered two elements, and this proved of greater importance, ultimately, than all the element discoveries of the period put together.

FIRE

Of all the substances viewed as elements by the Greeks, certainly fire was the most dramatic. It alone blazed with light. It leaped and danced, and changed its shape at every moment. It seemed the very embodiment of impermanence.

In the sixth century B.C. there lived a Greek thinker known as Heraclitus (c. 540–c. 475 B.C.). He lived in Ephesus on what is now the Aegean coast of Turkey and was known to the later Greeks as the "weeping philosopher" because of his pessimistic view of life. To him, nothing was eternal, nothing stable. All was evanescent, everything changed, everything came into being and was eventually destroyed.

To him, fire was the symbol of change and destruction and it was fire (or some ideal version of fire) which he therefore accepted as the basic substance of the Universe. Only through fire could the impermanence of the Universe be explained. Paradoxically, Heraclitus maintained that the only thing that was unchanging was change and that only fire, then, was eternal and basic.

In the course of the next two centuries, Heraclitus' concept was tamed and made less radical. Fire came to be accepted as merely one of the four elements that made up the Earth and its works, the other three being earth, air, and water.

Aristotle (384–322 B.C.) gave fire its place in his picture of the organization of the Universe. It was placed in the highest regions appertaining to the Earth; lying above the air. Ordinarily invisible, it appeared briefly as lightning when the air was rent by the fury of storms. Fire, when formed in the lower regions, tended to burst upward in an effort to reach its natural place on high. Thus fire shot up out of volcanoes, and even the small flames set by man strove upward.

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Through ancient and medieval times, fire, as a substance, resisted investigation. It could not be handled easily as earth and water could. Nor could it be trapped and studied as air could.

It could be used, however. It was used everywhere, in forming glass from sand, pottery from clay, metal from ores.

In all the various ways in which fire might be used, it produced, invariably, light and heat. Indeed, it was often used by man for no purpose other than to provide light and heat, to turn night at least a little into day, and winter at least a little into summer.

Light and heat were not alike as aspects of fire, however. Light existed only as long as the fire lived. When the fire died, the light was gone. Heat on the other hand persisted. Long after the fire died down, the kettle and its contents remained hot.

Could it be, then, that heat was the essential element to be considered? Were light and flame, the most visible and striking attributes of fire, merely a temporary accompaniment of heat rushing out and mixing with air?

The Dutch physician Hermann Boerhaave (1668–1738) was the first to distinguish between fire-as-heat and fire-as-flame and after his time, scientists began to think of heat and of flame separately. Gradually, heat began to seem the more fundamental.

The first to study heat in the modern sense was the Scottish chemist Joseph Black (1728–99).

If a kettle of water were placed over a fire, its temperature started to rise. Heat poured into the water, raising its temperature.

If, however, the kettle contained a mixture of ice and water, the temperature did *not* rise when it was placed over a fire. Instead, the ice melted, gradually. Only after the ice had all melted, did the temperature rise. The same thing happened when water was brought to a boil. The temperature rose until the boiling point was reached. After that, more and more of

the water boiled away but the temperature rose no higher no matter how fiercely the fire beneath roared.

Black tried to explain this in terms of a kind of heat-fluid which gradually filled the ice, melting it (or, at higher temperatures, filled the water, boiling it). It was not until the ice was saturated with the heat-fluid so that it had all melted, that there was finally heat fluid available for the water. Only after the ice had melted, then, did the temperature of the water begin going up.

The French chemist Antoine Laurent Lavoisier (1743-94) accepted Black's thinking on the heat-fluid. In 1789, when Lavoisier published the first modern textbook of chemistry, he included heat among his list of elements. He named the weightless heat fluid "caloric," from the Latin word for heat.

The theory of heat-as-fluid rather conveniently explained certain observations. For instance, substances almost invariably expand when they are heated, and it is easy to suppose that caloric takes up room. Why not? When it pours into the substance being heated, it naturally elbows the particles aside to make room for itself and the substance expands.

On the whole, the theory of heat-as-fluid satisfied the chemists, but it left the physicists with a gap in *their* theories.

Ever since the Italian scientist Galileo Galilei (1564–1642) had first studied motion quantitatively in the 1590s, physicists had been making more and more elaborate measurements. They had been particularly interested in those aspects of motion which did not change when the conditions of a particular group of bodies altered.

In 1668, for instance, the English mathematician John Wallis (1616–1703), dealt with the "momentum" of moving bodies, that is, with the product of their mass and velocity. He showed that he could successfully analyze the results of collisions between moving bodies by supposing that momentum could be transferred from one body to another, but could not be either created or destroyed.

This is called "the law of conservation of momentum." It

is the first-discovered member of a group of conservation laws which, taken all together, set the ground rules, so to speak, for all the changes that go on in the Universe.

Another type of conservation can be demonstrated by a ball thrown in the air. It moves more and more slowly as it rises, until at some point in midair, it comes to a halt.

But what we now call the "energy" of a body (its capacity to do work) depends in part on its motion. A moving ball will break a window or knock over a tenpin, but a stationary ball will do neither even if in contact with window or tenpin. Furthermore, the more rapidly the ball is moving the more spectacularly it produces its results on collision.

In the case of the ball rising into the air, the energy of motion ("kinetic energy") gradually diminishes and, when it is at a halt, the kinetic energy is zero.

But, high in the air, the ball has a certain energy by virtue of its position. If it were held there, it could do nothing, but once it is free to move, it falls at once and begins to gain kinetic energy. The higher in the air it is, the more kinetic energy it gains by the time it strikes the ground. The energy content by virtue of position is called "potential energy."

It would seem, then, that as the ball rises in the air, kinetic energy gradually turns to potential energy, and as it falls again the potential energy turns back to kinetic energy again. It is easy to show that the potential energy at the moment when the ball is motionless in the air is equal to the kinetic energy at the moment the ball begins to rise upward and also to the kinetic energy at the moment the ball completes its fall downward.

As the ball rises and falls, its kinetic energy is converted to potential energy and then back to kinetic energy without loss. What's more, at every point in its rise and fall, the kinetic energy *plus* the potential energy (together they are called "mechanical energy") remains constant.

Ideally, the ball, if it were perfectly elastic, would strike, bounce, rise to a height, fall, strike, bounce, rise to the same

height again, and so on indefinitely, changing back and forth between kinetic energy and potential energy forever

The effect is shown more elegantly by a pendulum, where the bob has its maximum kinetic energy at the bottom of the swing. If it is then heading leftward, it will rise more and more slowly, coming to a halt at a point where all the kinetic energy is turned to potential energy, drop back to the bottom faster and faster, swing to the right, come to a halt again at a point where all the kinetic energy is turned to potential energy—and so on, over and over and over.

The notion of conservation of mechanical energy gradually emerged in the course of the late seventeenth century, though most of the actual terminology (even the word "energy" itself) didn't come till the nineteenth century.

One of the difficulties with the law of conservation of mechanical energy was that it was imperfect. It could only hold under ideal conditions that could never be attained in actual practice. A bouncing ball reaches a lower height with each bounce and finally comes to rest. A pendulum's swing very slowly contracts and it finally comes to rest. More or less slowly, the mechanical energy disappears and, in the end, an object has neither energy of motion nor energy of position.

The villain in the case is friction: friction with the ground, friction with the air, friction with anything the moving object touches.

Could it be that the mechanical energy is somehow transferred to the ground or air or whatever? At first thought, this doesn't seem likely. After all, the matter accounting for the friction does not visibly gain either kinetic energy or potential energy. It neither moves nor changes position as a result of friction.

But is it necessary for the object supplying the friction to move as a whole or to change position as a whole? Suppose that apparently solid matter (or liquid, or gaseous) were actually made up of tiny particles far too small to be seen, and suppose that these tiny particles moved every which way in a kind of blur that was not visible to the unaided eye.

After all, objects could be warmed by friction. Perhaps, the invisible motion of the invisible particles of matter was what we called heat; and the faster the motion, the greater the heat. The loss of mechanical energy in visibly moving objects might then result from the transfer of that energy to the tiny particles of matter, which would gain a corresponding amount of mechanical energy. Another way of putting it is that friction converts mechanical energy into heat.

As early as about 1700, the English philosopher John Locke (1632–1704) was suggesting the idea of heat-as-motion (kinetic theory), which was eventually opposed to heat-as-fluid (caloric theory).

If heat were accepted as a form of motion, then the law of conservation of mechanical energy might be extended to include heat and it might then become less imperfect; or not imperfect at all.

The chief trouble with the suggestion was the notion of tiny particles too small to see, engaged in motions too subtle to detect. Scientists, generally, were not ready to accept so apparently mystical a concept and the law of conservation of mechanical energy remained as it was—imperfect.

Yet before the end of the eighteenth century, some strong blows were struck in favor of the kinetic theory of heat.

The first of these involved one of the more colorful characters in the history of science. He was Benjamin Thompson (1753–1814), who was born in Massachusetts. During the Revolutionary War, he was a Tory serving the British authorities as a spy. Naturally, when the British left Boston, Thompson found it safer to leave with them. He never returned to the United States.

In 1783, he left Great Britain for the Continent, and eventually entered the service of the Elector of Bavaria, who was pleased enough with the American's services to give him a title of nobility. Thompson chose to be titled after the town near which he had owned some land and became Count Rumford. It is by this name that he is usually known.

One of Rumford's tasks, in 1798, was to supervise the boring of cannon for the Bavarian army. The way this was done was to have a horse work a treadmill, the turning of which supplied the power that kept a borer turning. This borer forced its way into a solid block of brass, slowly forming a cylindrical hole of the required size.

As the borer worked, brass shavings were gouged out and these, together with the block itself, grew so hot that the metal had to be constantly cooled with water.

Rumford couldn't help but wonder where the heat all came from. According to the caloric theory, the breaking up of the solid brass into shavings released some of the caloric content of the brass into the air, where it was more evident.

To Rumford, however, this seemed nonsense. After all, how much caloric could be liberated in such a way? Certainly not more than the metal contained in the first place. Yet he calculated that if all the caloric released in the process of boring were put back into the metal, the entire block would melt.

He tried something else. He began with a partly excavated cannon and then began operations with a borer so blunt that it could not gouge out any further brass. The brass was now not breaking up and no caloric ought to be released. Yet heat was developed in even greater quantities than when a sharp borer was used.

Rumford pointed out that heat was produced without fire, without light, without chemical combustion. It came just out of motion, out of the turning of the borer and the treadmill, out of the motion of the horse. He maintained that heat was a form of motion and that heat would be formed endlessly as long as horse, treadmill, and borer moved.

Then in 1799, the young English chemist Humphry Davy (1778–1829) also tackled the problem. He worked out some interesting demonstrations with friction. He used clockwork to make a metal wheel turn against a metal plate. Though he kept the entire system below freezing, enough heat was developed to melt the wax with which he had coated the plate.

In the same series of experiments, he rubbed two pieces of ice together by a mechanical setup and, though the temperature was again kept below freezing, the ice melted.

The point was clear. If there was insufficient caloric in the entire system to raise the temperature above freezing, how could the release of only some of that insufficient quantity produce enough heat to melt ice and wax?

Again the conclusions seem to be that there was no such thing as caloric and that heat was kinetic in nature, a form of motion.

The calorists defended their position vigorously, of course. When, however, in 1803, less than five years after the experiments of Rumford and Davy, the English chemist John Dalton (1766–1844) began to advance his atomic theory, it might have seemed that the calorists had received their deathblow. After all, Dalton's reasoning in favor of atoms was so strong that many chemists began to accept it at once and here was the refutation of the strongest point against the kinetic theory of heat. Matter *was* composed of particles so tiny as to be invisible and surely these particles might be invisibly in motion.

As it happened, though, the early atomists were also calorists. Dalton himself used the caloric theory to explain the existence of gases.

According to the atomic theory, atoms were in contact in liquids and solids; but in gases, the atoms had to be far apart from one another. Only by so much wide separation could it be explained why gases were so much lighter than were equal volumes of liquids and solids, and why gases could so easily be compressed, whereas liquids and solids could not be.

But what kept the atoms of gases so far apart? Since gases are formed when liquids are heated, Dalton suggested that gases had gained so much caloric that all the atoms were surrounded by it. They were atomic islands embedded in weightless caloric seas.

Thus the caloric theory survived the coming of the atoms and competing kinetic theory of heat made no headway. The

latter was not, however, forgotten. Stubbornly, some physicists kept returning to it.

It was clear that if, indeed, a certain amount of mechanical energy (whether kinetic, potential, or a combination) could be turned into heat, then, if energy was to be conserved, the mechanical energy had to be turned into a *fixed* amount of heat. How much energy meant how much heat? What, in other words, was the "mechanical equivalent of heat"?

Rumford had made a rough estimate to the effect that (using modern units) 5.55 joules of work was equivalent to 1 calorie of heat. In 1842, a German physicist, Julius Robert von Mayer (1814–78)—he was born in the year Rumford died—offered a new figure on the basis of a single experiment in which a horse-powered device stirred paper pulp in a caldron. This was 3.90 joules per calorie, which was much closer than Rumford's value to that which is now accepted.

Mayer also advanced a startling insight. He claimed that energy was perfectly conserved *if all its manifestations were included*. One had to take into account not only mechanical energy and heat, but light as well, and electrical energy, magnetic energy, and so on. Even the energy of living things must be included.

Energy might change its form in a dozen different ways but when, within a particular "closed system" (one which did not lose energy to, or gain energy from, the outside world), all the energy was added up, the sum remained constant always, no matter what changes took place within the system.

However, Mayer's enunciation of the "law of conservation of energy" went utterly unnoticed. It was too daring an idea, too far in advance of experimental data.

Even as Mayer worked, however, the insufficiency of data was being corrected.

An English physicist, James Prescott Joule (1818–89), who was unaware of Mayer's work, was tackling the problem of the mechanical equivalent of heat. For years he worked to determine this value in a score of different ways, using every form of

energy he could handle. He heated water and mercury by churning them with paddles. He passed water through small holes to heat it by friction. He expanded and contracted gases. He used electricity to heat water. Even on his honeymoon, he made use of a special thermometer to take the temperature at the top and the bottom of a waterfall.

In the end he found that a given amount of energy *of whatever form* always yielded the same amount of heat, and he set the mechanical equivalent of heat at 4·18 joules per calorie. (He didn't use the unit "joule," of course, nor is the similarity between that and his name a coincidence. The joule was invented later, set equal to 10,000,000 ergs, an older unit, and named in his honor.)

Joule found it difficult to get his results published in a learned journal. He lacked a professional appointment, for one thing, and that made him seem an amateur. For another, he was presenting results which depended on tiny temperature differences; differences which most physicists at the time felt were too small to determine with the necessary precision.

Joule was therefore forced to present his views in a public lecture in Manchester, England, in 1847. Having done that, he managed to persuade a reluctant Manchester newspaper to print the lecture in full. In this way, he at least managed to assure himself of credit for his findings.

A few months later, he finally had a chance to present it before a scientific gathering. The audience was unsympathetic and when he was finished, they sat in stony silence, until a young Scotsman, William Thomson (1824–1907), who was in later life to become Lord Kelvin, rose to ask a question. Thomson's shrewd questioning and Joule's clear answers began a lifelong friendship between the two and their enthusiasm at this time infected the audience. Joule was taken seriously at last.

In that same year, 1847, a young German physiologist, Hermann von Helmholtz (1821–94), presented a paper that maintained the conservation of energy in precisely the same terms that Mayer had done five years before (though Helmholtz had

not heard of Mayer's work any more than Joule had).

For a time, Helmholtz could not get his paper published, but under the hammer strokes of Joule's experimental labors, more and more physicists were rallying to the kinetic theory of heat, so the notion of a law of conservation of *all* energy had to be accepted. The notion of caloric tottered to its fall.

Helmholtz was given the credit for the discovery of the law of conservation of energy at the time. Mayer's claims to priority were rejected and he was treated as a plagiarizing crackpot—to the point where frustration drove him to mental collapse and attempted suicide. He survived to receive his due credit in the last decade of his sad life, however.

Nowadays, the credit for the law of conservation of energy, sometimes considered the greatest and most fundamental of all the laws of nature, is shared among Mayer, Joule and Helmholtz.

Two others might be added, though Ahead of all of them was a French physicist, Nicolas Léonard Sadi Carnot (1796–1832), whose studies of the steam engine cycle in 1824 showed the relationship between mechanical energy and heat. Carnot, however, died prematurely of cholera and his single publication went unnoticed until the 1840s. There was also a Danish physicist, Ludwig August Colding (1815–88), who in the 1840s independently advanced notions of a mechanical equivalent of heat and of the conservation of energy.

The relationship of the motion of atoms to temperature and heat was placed on a firm theoretical basis about 1860 by the labors of the Scottish mathematician and physicist, James Clerk Maxwell (1831–79). The work was further extended by the Austrian physicist Ludwig Eduard Boltzmann (1844–1906), who made Maxwell's mathematics more rigorous.

In this way, the kinetic theory was completely established on the basis of random motions of atoms and molecules, and caloric was killed forever.

The tragic fate of those involved with kinetic theory continued, however. Maxwell died prematurely of cancer. Boltz-

mann's situation was even worse. He was subject to fits of depression, aggravated by last-ditch opposition to kineticism on the part of some scientific conservatives, and in the end Boltzmann committed suicide.

But we can see now that the Greeks' choice of fire as one of the elements of the Universe was a tribute to their insight. If we consider fire as the most obvious and dramatic form of energy available to ancient man, we can appreciate the insight better.

It is of energy in all its forms (and even matter is but a form of energy) that the Universe is constructed. What's more, energy is eternal, can neither be created nor destroyed, and every change in the Universe from the explosion of a galaxy to the motion of an electron is an aspect of energy change.

So it follows that the old sage Heraclitus was quite right after all. Fire is (in a subtle way) the fundamental substance of the Universe and the basic unchanging factor in a changing Universe.

AFTERWORD

When *Smithsonian* asked me to write the preceding four articles on the four Greek elements, I'm not sure what they had in mind, but it occurred to me to use them as the base for a quick overview of the history of chemistry.

By the end of the fourth article, however, I had only reached the latter end of the nineteenth century. It occurred to me that the Greeks had a fifth element "ether," one suggested by Aristotle. I could write a fifth article based on ether that would carry me well into the twentieth century. I suggested it to *Smithsonian*, which, however, had had enough.

So—anyone else want it?

4 • In Physics

SPACE

Space is what makes possible differences in position. We become aware of differences of position, and therefore of an extension within which those differences can exist, as a result of muscular effort. We must turn our heads, or at least our eyes, to see first one thing and then another. We must reach out our arms this way, then that, this far, then that, in order to make our fingertips coincide with this object or that. Or we must move bodily here, then there, to reach first this, then that.

The notion of space begins with the concept of "here, not there," or "there, not here." As soon as one can localize a particular object as being in one particular place, the idea of a limitless extension of potential place within which all objects are located becomes possible.

Naturally, the idea of extension does not have to be specifically formulated in the mind to be made use of. We can be reasonably sure that no species other than man has a clear idea of space in the abstract, yet all organisms that move seem to utilize the concept. The tigress that springs makes some obscure judgment, however mechanical and non-conscious, concerning the effort required to change her position from a starting point in space to another which will coincide with the position of her prey. The chameleon launching its tongue at an insect does the same for its tongue-tip. Even the growing tendrils of a plant climbing upward to the Sun, or the probing rootlets aiming at water are changing position in a manner designed to keep the plant alive and the organism thus makes a surely unconscious, but surely advantageous, use of the concept of space.

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How, then, does man's attitude toward space differ from that of all other organisms? Of course, he can communicate his thoughts about it through carefully modulated sounds. Two or more human beings can sharpen their abstract concepts by mutual mental friction. Still, for all we know, other species of organisms do the same in some way. It seems entirely improbable that this can be so, but we can never be certain what concepts exist in the brains of species other than our own, and how these may be communicated, unless we can learn to share in their communications thoroughly and they in ours.

What we can judge by, however, is deeds, not thoughts. We can take the attitude that it doesn't matter what an organism thinks or understands about a particular concept, for that we might never know. What counts is what an organism *does* about a particular concept.

The tigress and the chameleon judge distance, but they do so intuitively, guiding muscular effort by the subtle adjustments of the focusing mechanisms of their eye. (We do that, too, every time we pick up a pencil, or do almost anything else.) The beaver in building a dam, or the bird in building a nest, makes use of logs and twigs that are more or less of the right size for the purpose, but there is at best a hit-and-miss quality to the process, and the final decision is the attempt at a direct fit, which either succeeds or fails.

Here, though, mankind's approach to space is unique. Alone among the species, he goes beyond simple trial and error in comparing two or more sets of differences in position. In other words, man *measures* distance (the separation of position) in a mechanical way and thus reduces the notion of extension in space to a form that makes possible accurate comparisons without superimposition.

He might begin by placing a log across an opening until he finds one that is sufficiently long to stretch across without falling in (if he wishes to construct a barrier across a cave opening). The log that fits can then be used as a reference log against which other logs are measured so that no effort is wasted bringing back logs that are too short. It is simpler, though, to

use a handspan and count, and that is the truly crucial addition—the use of counting.

There are so many handspans across the log that fits; therefore you need find other logs that are as many handspans across. You might even learn to break a too long log to leave one of the proper length. You don't need a reference log in that case; you need only carry your hand—provided you possess also the ability to count and remember the count.

There are a variety of parts of the body that can be used to make measurements of various sizes, and their imprint leaves a mark on common measures today. The foot is exactly what its name implies, the length of a foot. The height of horses is measured in hands, and the "mile" is from the Latin *milia passuum* or "a thousand paces."

As long as measurements are private, the advance over the situation in other species is small. The human would be more efficient than the beaver at finding logs of the right size, but not very much more so, if each man worked alone. But to communicate your measuring system to others, and thus establish a community of labor, produces problems, since the foot or pace of one person is not the same size as that of another.

To suit a number of different people there must be developed the notion of a "standard measure." Everyone will use the chief's foot as a way of measuring the length of logs; and since the chief would not be available for everyone's measuring (nor wish to be) it would occur to some genius to produce logs measuring exactly the length of the chief's foot and distribute them to those who need to have measures in common. It would be the "standard log" once again, but the same for all, and adaptable to all purposes, particularly if it is neatly subdivided into still smaller units.

When did the notion of a standard measure arise? Surely it could not have come much later than the development of agriculture, about 8000 B.C. or so. It is very likely men could not cultivate their farms in peace unless there were some agreement (by measurements according to some accepted standards) as to how wide a piece of land belonged to each. The simple

use of boundary stones invited surreptitious shiftings.

By the time civilization developed to the point of the invention of writing, elaborate systems of measurement were in use, and it was considered an important part of the governmental apparatus to maintain the integrity of the standard measure. That integrity was even made part of the divine command. Thus, as part of the pronouncements of God upon Mt. Sinai (according to the biblical story) we have, in the words of the modern translation, the New English Bible: "You shall not pervert justice in measurement of length, weight, or quantity. You shall have true scales, true weights, true measures dry and liquid. I am the Lord your God who brought you out of Egypt." (Leviticus 19:35–37.)

The next important step in the understanding of space came with the development of geometry, the study of interconnected measures. By understanding the relationship of one part of a figure to another, it became possible to measure the length, let us say, of one part and from that deduce the length of a second part *without* actually measuring it.

For instance, it is quite impractical to measure the height of the Great Pyramid directly, since one cannot stand at the apex, bore a hole to the ground through its rocky structure, drop a plumb line through the hole and then measure the length of line needed to reach the ground. However, one can measure along the slope of the pyramid from ground to apex (if one wants to climb it and drag a cord behind him). From that, and a knowledge of the angle the slope makes with the ground, one can *calculate* the height of the pyramid.

Even this is an arduous task, requiring much muscular effort, and a line that is about 615 feet long. The next step is to be able to relate the measurements of one figure to that of a second figure which is easier to handle. A small triangle, for instance, would have the same measurement relationships as would another, much larger triangle of the same shape, so why not work with the convenient former rather than with the inconvenient (perhaps impossible) latter?

There is a story that the Greek philosopher Thales, about 570 B.C., measured the height of the Great Pyramid without ever climbing a foot. He noted that when the Sun was in a certain position in the sky, his shadow was the same length he was. (He and his shadow formed the two legs, we would now say, of an isosceles right triangle. He presumed this was true for all objects at this time. He therefore measured the distance from the edge of the base of the pyramid to the shadow of its apex on the ground (something much easier to do than measuring the slope by climbing it) and added to it the distance from the edge of the base to the center of the large square on which the pyramid stood (an easy calculation).

All such measurements of objects not directly accessible, can be reduced to the manipulation of triangles of similar shapes and that branch of mathematics is "trigonometry."

The climax reached by trigonometry, as far as our planet was concerned came in 240 B.C., when a Greek philosopher, Eratosthenes, working in Alexandria, Egypt, measured the size of the entire Earth (and accurately) without ever leaving home, and certainly without wrapping a measuring tape about its fat girth.

Travelers had told Eratosthenes that in the city of Syene (the modern Aswan) in southern Egypt, the noonday sun was directly overhead at the summer solstice so that every object stood on its own shadow. On that same day, however, Eratosthenes could tell that the noonday sun in Alexandria was seven degrees south of the zenith—by measuring the length of the shadow as compared with the length of the object casting the shadow.

This difference, Eratosthenes realized, was due to the curvature of the spherical Earth. The Sun looked down (so to speak) directly on one part, but looked at the surface somewhat to the north of that part at a slant because the surface curved away. There are 360° to a circle and the distance from Syene to Alexandria represented 7°. The entire circle of the Earth was therefore about 360/7 or some fifty times that between the two cities. The north–south distance between Syene and Alexandria

was 500 miles, so the circumference of the Earth was 25,000 miles.—And so it was.

Until the time of the Greeks, there was no way of making measurements of distance anywhere but at or very near the surface of the Earth. No one could rise up through the atmosphere, trailing a measuring cord. Nor did there seem any way to compare distances in the sky and get any but the most primitive notions. It was clear, for instance, that the Moon passed in front of the Sun during solar eclipses, so the Moon was closer to the Earth than the Sun was.

Less obvious reasoning gave rise to the notion that both Moon and Sun, together with five bright stars that constantly changed position against the background of the other "fixed" stars, were closer to the Earth than those fixed stars were. From the rapidity of motion of these "planets" (from a Greek word meaning "wanderer") the Greeks decided their order of distance away from the Earth was the Moon, Mercury, Venus, the Sun, Mars, Jupiter, and Saturn.

This order is not exactly correct and the Greeks could redetermine nothing else. And without a real notion of heavenly distances, there could be no true understanding of the size of the heavenly bodies and the nature of the structure of the Universe. Mankind was forced to suppose that the heavenly bodies were, in actuality, exactly what they seemed to be. The stars were small specks of light, fixed to a solid sky that was blue in the day and black at night. The planets were fixed to other, closer spheres, that were perfectly transparent and therefore perfectly invisible. (For all anyone could tell, each sphere touched the one beyond.) And the Moon and Sun were spheres of light which were as small as they looked to be.

The Greek philosopher Anaxagoras, living in Athens, suspected that things were *not* as they seemed. The Sun might be a great distance off and, if so, though it looked small it might be a large glowing rock a hundred miles across. He said so about 435 B.C. and created a furor. He was forced into exile.

The first person to try to transfer to space the mathematical methods that worked on Earth was the Greek astronomer Aris-

tarchus. The Earth's shadow falls on the Moon during a lunar eclipse, and from the size of the shadow, Aristarchus argued, about 280 B.C., that the Moon was much larger than anything even Anaxagoras had suspected and presented the mathematics to prove it. At least one Greek philosopher, Cleanthes, believed he ought to be brought to trial, but Aristarchus weathered the storm better than Anaxagoras had.

About 150 B.C., the Greek astronomer Hipparchus (the greatest astronomer of ancient times) made use of trigonometry. He recorded the position of the Moon against the stars from two widely separated positions on Earth at the same time (naturally, two observers were required). This enabled him to draw an imaginary triangle from the Moon to two points on the Earth. He could measure the angle at the apex at the Moon in this way, and the length of the base of the triangle on the Earth. From this he could calculate the altitude of the triangle (which represented the distance of the Moon from the Earth) by comparing it with a small triangle of the same shape.

Hipparchus could show, then, that the Moon was at a distance equal to thirty times the diameter of the Earth, or 240,000 miles, if Eratosthenes' earlier figure of the size of the Earth was accepted. It meant the Moon was a body about 2,100 miles across.

In theory, the distance of any other heavenly body could be determined in the same way, but for all other bodies but the Moon, the size of the angle at the apex was so small that it was impossible to measure with the unaided eye. All Hipparchus could say was that all other heavenly bodies were much farther than the Moon.

But Greek science was steadily losing its vigor in Hipparchus' time. The vast distance of even the nearest heavenly body made little impact on a world turning away from scholarly probing of the Universe.

It was not until the seventeenth century that man's concept of space beyond the surface of the Earth was really altered radically and then it was not through any measurement in

heaven, oddly enough. It involved something very Earth-bound

It had long been known that it was impossible to pump water higher than thirty-three feet above its natural level. An Italian physicist, Evangelista Torricelli, wondered, in 1643, if a water pump worked by allowing the weight of air to push the water upward. In that case, when a water column reached a height of thirty-three feet, its weight per unit area was perhaps equal to that of air. Air, exerting its maximum force under those conditions could then hold up no more.

If this were so, then a liquid less dense than water could be pumped higher, one that was more dense than water, not as high. It would be convenient to experiment with short columns, so what about mercury, which was thirteen and a half times denser than water? Air should hold up a correspondingly shorter column of mercury, one only about thirty inches tall.

Torricelli filled a four-foot length of glass tubing (closed at one end) with mercury, stoppered the opening and upended it into a large dish of mercury. When he unstoppered the opening, the mercury began to empty out of the tube as one might expect, but it did not do so altogether. Thirty inches of mercury remained in the tube, supported by the weight of the air pressing down on the mercury in the dish.

Torricelli had invented the barometer, had proved that air had weight, had demonstrated that it was air pressure that made a water pump work. In addition, he had produced the first good vacuum that mankind had ever seen. When the mercury began to pour out of the tube, the space between the top of the mercury level and the closed end of the tube contained *nothing*, except for a vanishingly small trace of mercury vapor.

And he had done still more than that; much more.

The ancient Greeks had had the concept of a vacuum but didn't believe it could really exist. "Nature abhors a vacuum," said Aristotle, who felt the entire Universe was filled with matter of one sort or another.

But Torricelli had not only demonstrated a small piece of vacuum, but had indicated the whereabouts of an infinitely

larger piece. If air had only enough weight to support a column of mercury thirty inches high, and if it had the same density everywhere that it had near the surface of the earth, then the air was only five miles high. Even if air spread out and grew thinner as one traveled higher (as soon appeared to be the case) it would still be only a few dozen miles high before thinning out to such an extent that it might as well be considered vacuum.—And the Moon was 240,000 miles high!

Torricelli's experiment meant that, for the first time, mankind had to face the notion that the air made up only an exceedingly shallow shell of gas immediately surrounding the Earth and that beyond it lay mile upon limitless mile of *nothing*—of vacuum—broken only occasionally by some heavenly body.

It was with Torricelli that there arose the notion of "outer space" as a special entity of limitless nothingness.

Then in 1672, the Italian-French astronomer Giovanni Domenico Cassini worked out the distance of Mars by trigonometry. (He had a telescope, which Hipparchus had not, and could measure tinier angles.) By that time the true structure of the solar system was known, thanks to the Polish astronomer Nicolaus Copernicus and the German astronomer Johann Kepler, so from Mars's distance, all other planetary distances could be calculated. As the measurement was refined, it turned out that the Sun was over 90 million miles from the Earth and Saturn was nearly 900 million miles away. Other planets still more distant, were discovered, and their distances measured.

The vast distances of empty space were dumbfounding, and yet man was only at the beginning. The position of certain stars were determined at two times, six months apart, when the Earth was at opposite ends of its orbit about the Sun. With a base line over 185 million miles across, a triangle could be measured with its apex at a star called 61 Cygni, for instance.

In 1838, the German astronomer Friedrich Wilhelm Bessel announced the distance of that star to be 35 million million miles away. It was already known that light traveled at the

unheard-of speed of a little over 186,000 miles per second, but even at that speed, it took light six years to reach 61 Cygni (or to reach us from 61 Cygni), so that the star was said to be 6 light-years away.

The closest star, Alpha Centauri, is 4¼ light-years away, but astronomers probed ever outward, ever outward, with ever newer and more subtle techniques and they can now detect heavenly bodies which are 9 billion light-years away from Earth.

Space is much vaster than anyone would dream, just looking at the sky, and by developing the act of measuring a handspan to the point of being able to measure a trillion trillion handspans, something indescribable in dimension could be dimly grasped.

And even so, not entirely. It is not by measuring space alone that we can learn about space. There is the question of time, a concept perhaps even more elusive than that of space, which began as something altogether distinct from space and ended--

However, let us continue that part of the story next article.

TIME

From the first, time seemed to be something completely different from space. The concept of space involved the sense of sight and touch, to begin with. Something is *here*, not *there*.

Time is much more subtle, involving an inner sense of duration. First it is day, then it is night; first one eats and then one is hungry again. The concept of *first* and *then* implies the passage of time.

Learning to measure duration and getting a quantitative sense of time was more difficult than learning to measure distance and getting a quantitative sense of space. It was easy to pace off distance; not so easy to pace off duration. The sense of duration was all the more difficult to measure in that it was so subjective. A night in which you stand in a cold rain on sentry duty seems interminable; one spent with a sweetheart seems to pass in a twinkling. The same period of time may seem long to one person and short to another, depending on circumstances.

In order to come to some agreement, men had to use some external phenomenon that was periodic; that is, that was judged to be repeating its actions over and over at fixed intervals of time. The earliest periodic phenomena used for the purpose were the motions of the heavenly bodies. Thus spring came at yearly intervals, the new moon at monthly intervals, and sunrise at daily intervals.

It was not until the seventeenth century that a man-made periodic motion was found superior. The swinging pendulum made the modern clock possible and for the first time in history man could measure time by the minutes and seconds. This was followed by the vibrating spring and finally, in the twentieth

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century, by the vibrating atom. Modern time-telling devices can split the second into a million parts easily, and time can be measured with greater facility and greater precision than space.

But are space and time truly independent? Subjectively our concept of space is intertwined with our concept of time. We could get no sensation of separation in space without a separation in time, too. We have to turn our head to look first at one thing, then another, and this would have no meaning unless we looked *first* at one thing, *then* another.

If, in pacing off a distance, we find that one is twice as many paces long as a second, we also find that it takes us twice as long to pace off the first as the second. Even today, someone buying a house, for instance, has to consider its distance from a school or from his place of business—with the automatic thought that this will affect travel time. Space and time melt together.

To be sure, the melting isn't perfect. There are ways of measuring distance that are less direct than pacing off and are not so immediately dependent on time. A long distance can be measured by triangulation, for instance, in about the same time as a short distance. Again, it is easily possible to travel a hundred miles by superhighway more quickly and easily than ten miles through crowded city traffic.

Then, too, advances in transportation have altered the relationship of space and time for mankind generally. First the railroad, then the airplane, and then the jet plane, have associated the sensation of a given distance with a radically smaller sensation of duration. In colonial days, it was barely possible to breakfast in New York and lunch in Poughkeepsie; nowadays it is easily possible to breakfast in Paris and lunch in New York.

But the reaction to this? Invariably it is: "The world is getting smaller." The lessening of time is interpreted as a lessening of space.

Truly, though, all this is subjective and you can argue that a distance as a physical separation of two points possesses some

quality that is not affected by any change in the time it takes to go from one to another.

Let's consider *objective* connections between space and time. Real objects in the universe can only be located if at least three measurements are taken. Suppose you have a glass cube with an air bubble in it sitting on a table top, and with its sides facing due north, south, east, and west. To locate that air bubble, you must measure how far it is above the table top, how far from the north side, and how far from the east side. This gives the exact position in the up–down direction, the north–south, and the east–west. Only one point in the cube can correspond to all three measurements.

You can pick some other system of making measurements, but it will always be necessary to make at least three of them to pinpoint a particular spot. Hence, space is said to be "three-dimensional," where dimension comes from a Latin word meaning "to measure out."

But suppose that instead of a gas bubble in a glass cube, you are considering a fly in an empty cubical room. You could locate the fly by giving three measurements and if you looked at the point indicated by those measurements, you would find the fly wasn't there after all. It is flying and has changed its position since the measurements were made. Not only must the spatial distances be defined then, but also the time, so that you can describe not only exactly where the fly was, but exactly when it was there.

Three dimensions are sufficient only for a motionless, unchanging universe. As soon as any motion is introduced, any change, then the measurement of time is also required to locate any object. The Universe as we know it, then, is not three-dimensional at all, but four-dimensional.

And yet the four dimensions are not equivalent. We can take a cube and twist it so that what was east–west becomes north–south and vice versa. Or we can twist it so that east–west becomes up–down and vice versa. All three dimensions that seem to involve space only (the three "spatial dimensions") are com-

pletely equivalent, in other words, and which is which depends only on the orientation of the observer.

Time, however (the "temporal dimension") is not equivalent to the others in this fashion. There would seem to be no way in which a cube can be twisted so that what was first in the up-down direction is placed in the yesterday–tomorrow direction and vice versa.

Then, too, there is free progression in either direction in all three spatial dimensions. One can move right, then left, and return to the starting place; or forward, then backward; or up, then down. One can move quickly or slowly, at will, in any of these directions.

In the temporal dimension there seems no question of varying direction or speed at will. You and I and the whole Universe seem to be progressing forward along the temporal dimension in one direction and one direction only—from yesterday toward tomorrow—without any chance of reversing. What's more, the progression seems to be at one constant, unalterable speed.

Science fiction writers have dreamed of finding some device that would make travel along the temporal dimension to be as easily controlled as along any of the three spatial dimensions. First to do so was H. G. Wells in 1895 in his novel *The Time Machine*. Many (including myself) have used time machines since, but such a device is not practical and, as far as science now knows, will never be. Time travel, in the sense of moving freely backward and forward, at will, along the temporal dimension, is impossible.

And yet, if we can move only forward in time, it seems that it doesn't always have to be at a fixed unalterable rate after all—

In 1905, Albert Einstein advanced his "Special Theory of Relativity." Its view of the universe seemed bizarre at first but physicists have checked it a number of times and in a number of ways and it has met all tests without exception, and so triumphantly that no physicist now doubts its validity.

Among other things, the Special Theory pointed out that the measurement of distance depended upon the relative motion between the object being measured and the device doing the measuring.

Imagine two spaceships, A and B, each 360 feet long, passing each other in space in opposite directions, with each able to measure the length of the other instantaneously as it passes. If they pass each other at the kind of velocities we are used to, then each would be measured as 360 feet long by the other. Actually, the length would be a bit less than 360 feet long, but such a trifling tiny bit less as to be unnoticeable.

The shortening would become more noticeable as the velocities grew greater. Suppose they passed at a velocity of 1,000 miles per second, relative to each other. A would then measure B's length as 359 feet and B would measure A's length as 359 feet. This would grow more extreme as the velocity relative to each other continued to increase. If they passed each other at 162,000 miles per second, each would measure the length of the other as 180 feet, only half its "rest-length." And at 186,282 miles per second (the velocity of light in a vacuum) each would measure the length of the other as 0 feet.

At all velocities, A and B would each appear normal to itself, with its full length of 360 feet. The people on board A would maintain they were motionless and normal, while it was B, flashing by at high speed, that was shortened. The people on board B would say the same thing in reverse.

And both are correct!

To see why, consider that an American considers a Russian to be speaking a foreign language and a Russian considers an American to be speaking a foreign language. And both are correct. The quality of foreignness depends on who is doing the judging—and the quality of length depends on who is doing the measuring.

As it happens, the Special Theory of Relativity requires that the same thing happen to time.

Suppose that men on each ship have methods for testing the rate at which a clock on the other ship is going. As A and B

flash by each other, it will seem to men on A that the clock on B has slowed down. Indeed, to the men on A, all motions on B, even atomic vibrations, will have appeared to slow down by an equivalent amount. In other words, it will seem to men on A that the progress of time itself has slowed on B. On the other hand, to men on B, it will seem that the progress of time has slowed on A.

If they flash by each other at a velocity, relative to each other, of 162,000 miles per second, each will measure the progress of time on the other to be just half normal. If the speed relative to each other is 186,282 miles per second, each will measure the progress of time on the other to be 0. To the men on A, it will seem that time is standing still on B; and to the men on B, that it is standing still on A.

Can we still say that both are correct? Perhaps not, in this case. To see why, let's go back to length.

Suppose we wondered whether one of the two ships might really have shortened its length during the flash-by. One way to decide that would be to have one of the ships slow down, turn around and catch up with the other. When they are side by side, the lengths can be compared and we can see if one is shorter than the other.

Once side by side, however, the two ships are at rest relative to each other and each measures the other as normal in length. Neither is shortened.

Of course, one may have been shorter than the other while they were moving relative to each other, but that leaves no marks. There is no way of telling, by looking at a body at rest, that it was once shortened while it was moving.

Does the same thing hold for time? Not quite. When the two ships come together again, the rate at which time is progressing is the same on both, and both ships will agree to that, for now each is at rest relative to the other. However, past difference in rate of time passage does indeed leave a mark.

Suppose the two ships had started their flight with a clock marking exactly 1 P.M. on board each. If the time rate on B was actually slower than that on A at any time, the clock on B

would now be behind the clock on A. The situation would be the same (in reverse) if it had been A that had been experiencing the slower time rate.

The men on A have observed time to be moving more slowly than normal on B. Therefore when B pulls up to A, the men on A expect the clocks on B to be behind clocks on A. But the men on B have observed time to be moving more slowly than normal on A; and it is the clocks on A that they expect to be behind.

Well, which is it? Is neither clock behind? Do they record the same time? In that case, when did one catch up with the other? If B was observed by A to be running on slow time, it would have had to catch up in order for the clocks to be equal; it would have had to race ahead to make up for lost time, and that seems impossible. There is nothing in relativity that would allow any clock ever, under any circumstances, to move at faster than normal time-rate, so B could never catch up to A. But the men on B would argue, by precisely the same reasoning, that the clock on A could never catch up to the clock on B.

Well, then, what happens when the ships come together that will supply the answer to this "clock paradox"?

Actually, the Special Theory of Relativity is inadequate to deal with the situation. It applies only to objects moving at constant velocity; that is, at the same speed and in the same direction forever. This means that A and B, having flashed by each other, must continue to separate forever if the Special Theory of Relativity is to be invoked. They can never come together again to match clocks, so there is no paradox.

In 1916, however, Einstein broadened his concept to include objects that accelerate—that is, change their speed or direction of travel, or both. To do this he produced his "General Theory of Relativity."

As long as two ships are moving at constant velocity with respect to each other, there is no way of choosing one over the other as the one whose measurements are more valid than the other. As soon as one ship begins to slow down, turn about,

and catch up, it is accelerating. The situation with regard to the two ships is no longer identical, for one is moving at constant velocity and one is not.

The General Theory of Relativity shows that it is the ship that undergoes acceleration which experiences a real change in rate of time. The ship that undergoes acceleration will end with its clock behind when the two ships approach and compare.

But was it B that accelerated? The men on B could argue that to themselves it seemed that they were at rest and that it was A that accelerated in such a way as to effect a meeting. After all, each ship seems motionless to the men on board, no matter how matters seem to an observer outside the ship.

One argument against this is that B had to use its rocket engines, or some sort of energy, to slow up (relative to A), change its course, and approach A. No matter how the men on B might argue that they were at rest and that it was A that accelerated, the fact would remain (and the men on B would have to agree) that it was B that used its rocket engines and not A.

An even stronger argument rests on the fact that when B used its engines to accelerate, it did so not only with respect to A but with respect to the Sun, the planets, and all the stars and galaxies in the Universe. This involves an enormous asymmetry. You can see that B had to observe not only A accelerating its motion relative to B but the entire Universe accelerating its motion relative to B in a corresponding fashion. A, on the other hand, observed only B accelerating; the rest of the Universe remained in place.

The slowing of time is real, then, and it holds for the object that is undergoing accelerated motion relative to the Universe, generally.

In fact, under the General Theory of Relativity, motion through time becomes so intimately related to motion through space that it is impossible to consider space and time separately. Instead, one has to speak of "space-time" and the equations of

General Relativity include all four dimensions, though time is treated with some mathematical difference.

Imagine next a space traveler heading for a distant star and accelerating to a high speed in order to get there as soon as possible. If he reaches a speed of 162,000 miles a second heading away from us, and if we can measure the rate at which time is passing on his ship, it will seem to us that time is going at half speed for him. To himself, the space traveler will feel time to be progressing at its usual rate, but if he could view Earth (which is receding from him at 162,000 miles a second) and measure its time rate it will seem to him that it was everything on Earth that was moving at half speed.

It is, however, the space traveler who had accelerated with respect to the rest of the Universe to reach his velocity with respect to Earth. Earth did not have to accelerate with respect to the rest of the Universe to reach its velocity with respect to the space traveler.

It is therefore the space traveler who is *really* experiencing a slowdown in the rate of his progression along the temporal dimension.

Suppose a space traveler is moving at the velocity of 186,200 miles per second. For every hour that passes for him, thirty hours pass on Earth. If he travels for a year in this fashion (having accelerated instantaneously) and then turns around and comes back at this speed (having turned around instantaneously), he will find that while he has seemed to himself to have traveled two years, the men on Earth would claim he had been absent for thirty years.

Suppose the space traveler had left at the age of thirty, leaving behind a twin brother also aged thirty. When he returned he would be thirty-two, but his stay-at-home twin brother would be sixty. (That is why the "clock paradox" is sometimes called the "twin paradox.")

Of course it takes quite a long while to accelerate to a high speed, and a long while to make a turn and head back again, so conditions aren't quite as clear-cut as just described.

Still, suppose a space traveler could somehow travel at 186,282 miles per second, exactly the speed of light. Time would slow down to zero for him. It would seem to him, no matter how far he went, that no time at all had elapsed. Then, when he returned to Earth (assuming again it would take him no time to reverse his direction), he might be surprised to find that men on Earth were under the impression he had been away for a hundred years, a thousand, a million—depending on how far he had gone at light-speed.

So time travel *is* possible, in a way. By moving through space fast enough, you can move forward through time as well. But only forward; it is time travel *one-way*. Once our space traveler has moved thirty years or a million years into the future, he can never move back again.

But what, you might ask, if he went *faster* than the velocity of light? Wouldn't the time rate become less than zero? Wouldn't it become negative, in other words? And wouldn't he then move back in time?

Alas, no. The firmest rule in the Theory of Relativity, Special or General, is that any object that moves more slowly than the velocity of light in a vacuum can never, merely by accelerating, come to move faster than the velocity of light in a vacuum.

Time, therefore, can do no more than stand still. No one can ever go back in time by any method that as yet seems to fit in with the structure of the Universe.

MASS

It seems very natural to think of space as something that doesn't exist, but merely contains. We can think of it as just a vast emptiness which holds matter—and not very much matter at that.

It is possible that there may be as many as ten thousand billion billion stars in the Universe. If each star were as voluminous as our Sun, all these stars, put together, would nevertheless make up a volume that is only about a millionth of a trillionth of a trillionth of the volume of the Universe that contains them.

What's more, the stars themselves are for the most part empty space, in a manner of speaking. That is, they are made up of atoms, which are, in turn, made up of particles far smaller than themselves. If all the subatomic particles (the real matter of the Universe) in all the stars were packed together, each star would be, on the average, eight miles across. The matter in the Universe would then take up only a trillionth of the room that all the loosely packed stars now do.

Perhaps we can get an idea of what this means by tackling something closer to home. Imagine the huge Earth we live on to be hollow, a vast, hollow, spherical cavity eight thousand miles across. Imagine next an influenza virus, too small to be seen in an ordinary microscope, but large enough to be made out in an electron microscope.

Take this influenza virus and place it inside the hollow Earth; place nothing else inside at all. The volume of the hollow Earth would then be to the volume of the single virus molecule floating inside as is the volume of the Universe to the total volume of subatomic particles which it contains.

SOURCE: "Mass" appeared in *Electronic Age*, Autumn 1971.
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If the hollow Earth contained nothing but a single virus, we would certainly feel justified in considering it empty. The single virus would, as content, be totally insignificant. Might we not feel justified in thinking of the Universe as empty then? Of what importance can the incredibly small smattering of matter be to it?

But suppose we imagine an empty Universe, a really empty Universe, a completely empty Universe. And suppose there were some way in which we could observe it without being part of it. What conclusions could we come to concerning it?

None, really. In order to deal with the concept of distance within a Universe, we must begin by locating two points within it and using the separation between those two points as a unit of distance. In order to deal with the concept of duration, we would have to sense changes in that separation and accept some convenient segment of change as a unit of duration.

But if a Universe is completely empty, there is no way of locating two points within it; no way of noting separation or change, distance or duration. In short, there is no way of indicating the existence of either space or time. It is fair to say then that it is meaningless to speak of space and time in the absence of things contained in space and time. The container only exists and endures by virtue of the contents, regardless of how insignificantly small the contents might be in comparison.

Suppose, next, we imagine a Universe with a single piece of matter in it; a single featureless sphere. Imagine, further, that we can sense the rest of the Universe from a position at the center of the sphere. Now what can we tell about the Universe?

To begin with, we might suppose the single piece of matter is moving. There is something called the "first law of motion" which states that if any object in the Universe is left entirely to itself and is completely unaffected by anything else in the Universe, then, if it is moving at some speed, it will continue moving at that speed constantly and forever in the same straight-line direction. In the special case that its speed is zero, it would be "at rest" to begin with and it would stay "at rest" forever.

This law was worked out, nearly four centuries ago, from observations made in our own Universe with its trillions of trillions of pieces of matter, but it does not seem to depend on the number of pieces of matter present in the Universe. If, one by one, those pieces disappeared there seems no obvious reason why the first law of motion should cease to hold.

Consequently, you might suppose that the first law of motion ought to apply to a piece of matter that was alone in the Universe. In fact, you might even argue that it should *particularly* apply to that single piece. After all that one piece can't possibly be affected by anything else in the Universe, since there isn't anything else in the Universe. It ought to obey the first law of motion exactly; if it is at rest, it will stay at rest forever; if it is moving, it will move at the same speed in the same straight-line direction forever.

But how can we check that? All one can observe from the center of that lonely piece of matter is nothingness all around. Whenever we make the observation, there is nothing. The nothingness would be precisely the same if the piece of matter were at rest. It would also be precisely the same if the piece of matter were moving at any constant speed in any given direction. From all we can sense, then, we would have no way of deciding whether the single piece was at rest or was moving; and if it was moving, we could not decide how fast it was moving or in what direction.

A Universe with one featureless piece of matter in it would be as blank and as immeasurable as one with no matter in it at all.

Let us pass on, then, to a Universe with two featureless pieces of matter in it. We can suppose the two pieces of matter are relatively close to each other; close enough so that one can be sensed from the other. (If they were so far apart that one could not be sensed from the other in any way, we might as well say that there were two Universes, each with one piece of matter.)

In fact, let us suppose that the two pieces have the relative positions of the Earth and the Moon, and that a picture can be taken of one piece from the center of the other. (We can

imagine that each piece glows with light or can, in some other way, be detected.)

If we study the successive images of Piece A from the vantage point of Piece B's center, we will notice that Piece A gets brighter and dimmer, brighter and dimmer; or perhaps (if it shows a visible disc) that it gets larger and smaller, larger and smaller. We might suppose that it is really brightening and dimming periodically, or expanding and shrinking. Or we might suppose that its brightness and size remain unchanged really, but that Piece A is approaching Piece B and receding, approaching and receding. As it approaches it seems brighter and larger; as it recedes it seems dimmer and smaller.

Whatever the reason for it, there is a periodic change and therefore the concept of time becomes possible. If the change is assumed to be one of distance, then the concept of space becomes possible.

Now, though, we must ask how the situation would change if we were observing Piece B from the center of Piece A, instead of Piece A from the center of Piece B?

It would not change at all. From either piece, the other would approach and recede, approach and recede.

Then which one is *really* approaching and receding?

The only answer we can make is: There is no way of telling. We can, with equal justice, assume that either piece is at rest and find the other to be shifting position.

What's more, no matter how many other pieces of matter are added to the Universe, there is no way of telling whether any one of them is at rest while the others are moving. We can *assume* that some particular body is at rest and determine the positions and motions of all other bodies according to the distances and direction we measured from the place of assumed rest. But then we can equally well assume that some other particular body is at rest and determine a new set of positions and motions of all other bodies.

It may be more *convenient* to choose one body rather than another to be at rest, but never more *right*. No matter which body we assume to be at rest, the basic laws of nature we de-

done from the behavior of the bodies of the Universe will remain the same. (Which is fortunate, for the Universe would be chaotic otherwise and impossible to understand.)

What this means is that there is no such thing as "absolute rest," no body that is *really* at rest. Nor is there "absolute motion," determined by comparing positions of a moving body with that of something that is *really* at rest. Nor is there "absolute space" or "absolute time," determined by noting the progressive changes in position of a moving body compared to something that is *really* at rest.

All we can measure is motion, space, and time relative to some object. It is *convenient* to *pretend* is at rest. This gives you "relative motion," "relative space," and "relative time." It is because Einstein worked with these to build his system of the Universe that we refer to his "Theory of Relativity."

Another thing we can deduce from the behavior of the two pieces of matter is that something is wrong with the first law of motion. If both pieces were following the first law of motion, then Piece A would behave in one of a certain limited number of ways as observed from Piece B. It might remain motionless, neither approaching nor receding. It might recede forever according to some simple mathematical relationship that can be worked out. It might approach, reach some minimum distance (which would be zero if there were a collision), and then, if there were not a collision, recede forever.

One thing that would *not* happen under any circumstances, if the first law of motion were in operation, would be the periodic approach and recession, approach and recession.

Can it be that only one of the pieces is disobeying the first law of motion? No! From either piece, the other one will appear to show the periodic approach and recession. Since it cannot possibly be decided that the periodic motion belongs to Piece A only or to Piece B, it can only be concluded that *neither* piece is obeying the first law of motion.

But remember—the first law of motion states that a body will travel at a constant speed and in the same straight-line direction, *if* it is left to itself and is unaffected by any other

body. The fact that the two pieces of matter are not following the first law means that each is being affected by something else. Since there are only two pieces of matter in the Universe we are imagining, we must conclude that Piece A is somehow affecting Piece B, and Piece B is somehow affecting Piece A.

What is the nature of the effect? Can we be sure that all that is happening is the approach and recession? Can it be that Piece A is also moving sidewise relative to Piece B?

Perhaps, but how can we tell? If we see consecutive images of Piece A as seen from Piece B, we could only tell if there were sidewise movement by considering its position relative to other objects in the sky—but there are no other objects.

Well then, suppose we add a third object to the Universe, much farther away from Piece A and Piece B than those two are from each other. (We can imagine the third piece of matter to be where the Sun is with reference to the Earth and the Moon.)

Now we can use the third object, Piece C, as a background against which to measure the position of Piece A as seen from Piece B (or Piece B as seen from Piece A). The distance between Piece A and Piece C will progressively increase so that sidewise motion can be measured.

It will then be possible to decide that Piece A and Piece B are both moving in ellipses about a point located somewhere between their centers.* In the case of the Earth and the Moon, the point happens to be located only 3,000 miles from Earth's center, which is still 1,000 miles below Earth's surface, so at a casual inspection it would seem that the Moon was moving in an ellipse about an unresponsive Earth—but close attention will show the Earth is moving about the "center of gravity" of the Earth-Moon system just as truly as the Moon is.

* It is because they are moving in ellipses, flattened curves, that the distance between them changes periodically. If they had happened to be moving in exact circles about that point (as is possible but extremely unlikely) then the distance would have remained constant and if the Universe had contained only those two pieces of matter and nothing else, it would have seemed that each was following the first law of motion.

What's more, if we add a fourth object very far away, say at the position of the star Sirius, we can use that as a background and discover that Pieces A and B, even as they circle each other, are together moving in a grand sweep about Piece C (assuming that Piece C is much larger than Pieces A and B, as the Sun is much larger than the Earth and Moon).

The more pieces added to the Universe the more the effects of piece upon piece multiply and the more complicated things might be. Fortunately, the complications do not go beyond the capacity of the human mind to unravel, because the pieces of matter are usually so arranged that one piece or another is large enough, or close enough, to have by far the dominating influence over others in its neighborhood. By concentrating on the dominating influence in some particular group of pieces of matter, the nature of that influence can be puzzled out.

Three hundred years ago, Isaac Newton was able to show that the motions of the heavenly bodies could be satisfactorily explained by assuming that each body affected all the other bodies in accordance with a rather simple rule.

Any particular body in the Universe, he decided, attracted any other particular body by an amount that was proportional to the product of the masses of the two bodies and was inversely proportional to the square of the distance between their centers. In other words, the attraction between two bodies grew stronger when their masses were increased, and weaker when the distance between them increased. The attraction is called "gravitation" and Newton's rule represents the "law of universal gravitation."

But what is this "mass" that is suddenly being mentioned?

Actually, no one really knows. Mass is whatever it is about matter that produces a gravitational attraction and reacts to it. When the gravitational attraction exists between two bodies, the conclusion is that both bodies possess mass. From the size of the gravitational attraction it is possible to come to certain conclusions concerning the amount of mass in either body or in both. On the other hand, if there is no gravitational attraction

between two bodies, then one or the other (or both) does not possess mass!

It is usually considered that anything which has mass is "matter." By this criterion* a rock or a human being is matter, but a beam of light is not.

By Newton's rule, if Earth and Moon suddenly doubled their distance from each other, the attraction would be 2×2, or four times weaker than it was before. If they tripled their distance, the attraction would be 3×3, or nine times weaker. If, on the other hand, the distance were decreased, the attraction would become correspondingly stronger.

Again, if the distance between Earth and Moon were unchanged, but the mass of the Earth suddenly doubled (or halved) the gravitational attraction between Earth and Moon would be doubled (or halved). The same would be true if the mass of the Moon suddenly doubled (or halved). If *both* masses doubled (or if *both* were halved), the gravitational attraction would be quadrupled (or quartered).

But let's get back to Earth. Suppose we are dealing with the Earth and some small object on its surface, such as yourself. We can assume your distance from the Earth's center will always be the same as long as you remain on one spot on the Earth's surface; and that the mass of the Earth always stays the same, too. The only thing we can't be sure of is the exact quantity of *your* mass, and the gravitational attraction between you and the Earth will be greater or less according to whether your mass is greater or less.

It is the gravitational attraction between yourself and the Earth that you measure when you weigh yourself on an ordinary bathroom scale. You determine your "weight" in this fashion and this is often accepted as being equivalent to your mass!

Weight, however, is *not* identical to mass. If you weighed yourself on a mountaintop, you would be farther from the

* Einstein qualified this by speaking of "mass at rest" or "rest-mass", that is the mass of a body which is at rest relative to the observer; but that is another story.

Earth's center than when you were at sea level. The gravitational attraction between yourself and the Earth would be slightly weaker and you would weigh slightly less—but not because you had less mass, only because there was greater distance. If you weighed yourself on the Moon, you would be closer to the Moon's center than ever you were to the Earth's, and you would be standing on a body with considerably less mass than the Earth. The result of the combination of factors would be that your weight on the Moon would be one sixth what it is on the Earth—but not because *your* mass had changed.

It is more accurate, then, to weigh not only yourself, but also other objects which have a known mass, and compare the gravitational attraction on yourself and on them. Then changes in distance or in the mass of the body you are standing on cancel out and you get a truer notion of your own mass. This is what we do on the kind of scale in which we shove weights along a lever, or when we weigh objects in a balance with the unknown in one pan and standard weights in the other.

The question arises, now, how one body can affect another body across space? There is a quarter of a million miles separating Earth and Moon, and 93 million miles separating the Earth-Moon system and the Sun. What is it that can reach across that distance and produce gravitational attraction?

One way of looking at it is to suppose that the presence of mass distorts the fabric of the Universe.

To see what is meant by that, consider a two-dimensional analogy—Imagine a perfectly smooth, frictionless surface, extending in every direction for some distance above the surface of the Earth, with Earth's gravitational attraction pulling down at right angles to the surface.

If the surface were hard and rigid, a body would slide along it in a perfectly straight line and at a constant speed, something like a hockey puck speeding along smooth ice. It would obey the first law of motion.

Suppose, however, that the smooth surface is actually a very thin, rubbery material, which gives under the pull of the Earth

upon the mass of a body resting upon it. Each piece of matter on the rubbery surface would sink down, pulling the surface with it. The more massive the body, or the more the mass is concentrated into a small volume, the farther down it sinks. The entire surface is distorted in this fashion: greatly so in the neighborhood of the massive body, less so, farther away. The distortion is never quite zero, though, however far we go from the body.

Now imagine two such bodies on the surface, each in motion. Imagine that the fabric rises behind them and sinks in front of them without friction and without impeding the movement. As the less massive body approaches the more massive one, it slides down the sharp declivity produced by the latter. It moves faster and faster and may strike the body; or, if it passes by, it may slide partway down, whirl around, and go shooting up and out of the declivity on the other side. Seen from above it will have followed a curve called a hyperbola. If it made a particularly close near-miss, it would circle the declivity round and round in what would seem, from above, to be an ellipse, accompanying the larger body wherever it goes and unable to shoot out of the pit into which it has tumbled.

If you imagine an endlessly large elastic fabric of this sort with a vast and even gravitational attraction pulling downward, and place trillions of bodies here and there on it, you will have a bumpy and uneven surface. No part of it will be quite level, except where two or more slants will just happen to cancel each other out very temporarily. Every part of it will slope at a continually changing angle according to the movement of the various bodies and all motions will be affected by the slope.

If the fabric were invisible and were viewed from above, we would very likely conclude that there were mysterious attractions between all the various bodies and work out a law of attraction that would be like Newton's.

In a three-dimensional way, the picture outlined above is what Einstein visualizes the Universe to be. There is a subtle fabric of space which is distorted by mass and every piece of matter is sliding up and down gravitational slopes, so to speak,

and moving in closed ellipses or open hyperbolas, large or small; speeding up; slowing down; all in accordance with the immensely complicated and ever changing nature of the local distortions.

In that case, we might logically maintain that the Universe contains not just the actual matter in countless trillions of pieces but contains also the sum of the distortions each piece produces. Since the distortions are everywhere, the Universe is not nearly-empty after all. Quite the contrary: it is *full* and would be full even if there were only two subatomic masses in the Universe and nothing more.

The preceding set of three articles (like the set of four that went before it) is incomplete.

Electronic Age asked me to do a series of articles on "big concepts" in science. I thought a while and suggested six topics: space, time, mass, energy, life, and intelligence; to be done in that order because I thought I could make a connected story out of it in a way.

They agreed and I did the first three and was just starting on the fourth—so help me, the first sheet of paper was in the typewriter—when the phone rang and the news reached me that *Electronic Age* had suspended publication.

There are three more left to do, then, but meanwhile the succeeding article will talk about energy, even though it is not quite the article I would have written for the aborted series.

YOU CAN'T EVEN BREAK EVEN

What a pleasure it is to be young, and hopeful, and unsophisticated. All things are possible and we are ready, in our heart of hearts, to believe that a fairy godmother might just come and wave her wand and turn our rags into a lavish costume and our hovel into a mansion. Why shouldn't an enchanted ring exist somewhere which will, at a rub, load our pockets with gold and jewels? Or why should not a jinn, slave to our commands, build a castle for us in the twinkling of an eye and fill it with dancing girls?

If this has not happened, we might wistfully imagine, it is because we just haven't been lucky enough to find the fairy godmother, or the enchanted ring, or the jinn. All we need is that incredible stroke of luck and we will have something for nothing.

But never mind fairies, rings, and jinn; in the real world it is energy that is the prime mover of all

We can define energy as anything that makes it possible to do work; anything capable of bringing about movement against resistance. In that case, we see at once that there must be various forms of energy.

Heat will make a thread of mercury rise against the pull of gravity, light will turn the vanes of a radiometer against the slowing effect of friction; electricity will turn a motor, magnetism raise a pin, a moving bat hurl a baseball over the fence; exploding dynamite lift a boulder, a hydrogen bomb in action heave a mountain.

Heat, light, electricity, magnetism, motion, sound, chemical bonds, nuclear forces—all represent forms of energy, and all

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SOURCE: "You Can't Even Break Even" appeared in *Smithsonian* as "In the Game of Energy and Thermodynamics You Can't Even Break Even", August 1970 Copyright © 1970 by Smithsonian Institution.

are different forms of essentially the same thing, for one form can be freely turned into another

Electricity moving through a wire can produce light, and a paddle rotating rapidly in water can produce heat. Magnetism can be turned into electricity; chemical explosions into motion; nuclear reactions into sound; and so on.

We have now sharpened the problem of getting something for nothing, and can consider it realistically. Whatever we want costs us energy, for it is only energy (by definition) that will allow work to be done. To be sure, we may need other things as well, for to build a palace we need not only the energy to lift materials but also a certain architectural knowledge—but we need energy *at least*. Without energy, all the architectural knowledge in the world won't budge one grain of sand.

To get something for nothing, then, is just another way of saying that we want to create energy.

But alas, this apparently can't be done. In the 1840s, as a result of careful experimentation and measuring, several physicists came more or less simultaneously to the conclusion that energy cannot be created (see the earlier article, *Fire*). One form of energy can be converted into another, or transported from one place to another, but that is as far as it can go.

But wait, that isn't all. If energy cannot be created, neither can it be destroyed. When energy is used, it doesn't disappear; it merely goes elsewhere or is changed into another form. The light that streams out of a candle does not vanish; it heats up the air and surroundings about itself. The hot water in a kettle may cool down but the heat does not disappear; it is transferred to the outside world.

To express all this, we can say: "Energy can be transferred from one place to another, or transformed from one form to another, but it can neither be created nor destroyed."

Or we can put it another way: "The total quantity of energy in the Universe is constant."

When the total quantity of something does not change, we say that it is conserved. The two statements given above, then, are two ways of expressing "the law of conservation of energy."

This law is sometimes considered the most powerful and the most fundamental generalization about the Universe that scientists have ever been able to make

No one knows *why* energy is conserved and no one can be completely sure it is truly conserved everywhere in the Universe and under all conditions All that anyone can say is that in over a century and a quarter of careful measurement, scientists have never been able to point to a definite violation of energy conservation either in the familiar everyday surroundings about us, or in the heavens above, or in the atoms within.

The study of changes of energy from one form to another, or the transport of energy from one place to another, is called "thermodynamics" (from Greek words meaning "heat-motion") because the earliest studies of the sort were made on the manner in which heat flowed from one part of a system to another

For that reason the law of conservation of energy is sometimes called the "First Law of Thermodynamics." It is first because it is the starting point for all else in the study. Before you can come to any useful conclusions in thermodynamics you must accept the fact that energy can neither be created nor destroyed.

Once that is accepted, we might decide that even so we have not entirely lost. In the great game of the Universe, maybe we can still win If we can't get something for nothing, maybe the First Law will allow us to get something for *almost* nothing

For instance, heat is a form of energy and we can make it do work Suppose we take a quantity of heat and change it into work. In doing so, we haven't destroyed the heat, we have only transferred it to another place or perhaps changed it into another energy form. Why can't we then simply gather it up wherever it is and in whatever form, and use it again, and then again, and then still again?

If that is so, then even if we can't create energy out of nothing, we can at least start with just a little energy and make it do any amount of work. By using the energy of a burning

candle over and over we could move the world; and it would be a greedy man indeed who wouldn't be satisfied with that or who would complain he wasn't really getting something for nothing.

Alas, it sounds good, but it can't be done. The trouble is that once energy is used, it still exists, yes, but it is spread out thinner. The heat of the burning candle spreads out into the air all about and into all the things the warmed air comes into contact with.

To put that heat back to work again, it has to be collected from the surroundings and concentrated again so that the candle flame is re-created. Heat *can* be concentrated, energy *can* be collected—but it takes energy to do so, invariably more energy than the energy you are concentrating and collecting.

What is the sense in using fresh energy to collect dissipated old energy, and using more to get less? You might as well use the fresh to begin with. It would be more economical.

In short, in your attempt to use the same old energy over and over again, you would be using up more energy than if you made up your mind to use each bit of energy just once.

You can't get round it. What the First Law of Thermodynamics really means is that in the great game of the Universe, *you can't win!* You can't get something for nothing, or even for nearly nothing.

This is a hard thing to accept and the indomitable human spirit is bound to fall back to the next line of defense. If it is true that you can't win, then perhaps you can at least break even. In other words, given a certain supply of energy, perhaps you can at least turn it *all* into work.

This problem came up when the steam engine was first developed in the eighteenth century. To begin with, the early engines were extremely inefficient. Great quantities of fuel were burned but most of the energy was wasted in heating up the world generally; very little ended in such useful work as pumping water.

Naturally, one assumes that if one could only cut down on

friction, prevent the flow of heat in unwanted directions, make the general design more efficient, one could eventually build a machine that would turn all the energy into work.

The first person to point out that this was not so, that even a *perfect* steam engine could not turn all energy into work, was a French physicist named Nicolas Léonard Sadi Carnot.

He demonstrated, in 1824, that the steam engine did work because part of its system was quite hot (the part that consisted of steam) and part was quite cold (the part that consisted of the cold water that condensed the steam). The heat energy present was, in other words, in greater-than-average concentration in one place and in less-than average concentration in another. We can quite easily measure the heat-concentration, which we usually call "temperature." The fraction of the energy that can be turned into work by a steam engine depends, then, upon the *difference* in temperature between the hot part of the system and the cold part.

The greater the difference in temperature between two parts of the same system, the greater the fraction of the heat energy we can turn into work. This difference in temperature becomes a maximum when *all* the heat in the system is concentrated in one part and *none* is concentrated in another.

The trouble is that physicists have shown it is impossible to concentrate *all* the heat in a system in one particular part of it. Even to approach total concentration takes an enormous effort.

If a steam engine uses ordinary steam for its hot part and ice water for its cold, the difference in heat concentration or temperature is such that only 27 per cent of the total heat energy can be converted into work, even if the steam engine were perfect in every other respect, if it lost no heat to the outside world, if there were no friction, and so on.

This is true for any system which uses energy of any kind. To make any system useful, to allow it to turn energy into work, there must always be a difference in energy concentration in different parts of the system. There must be a high energy concentration here and a low energy concentration there, and

the work to be gotten out of the system depends not on the total energy, but on the difference in energy concentration within the system.

We can say: "No device can deliver work unless there is a difference in energy concentration within the system, no matter how much total energy is used."

That is one way of stating what is called the Second Law of Thermodynamics.

Since there is never any way of reaching an ultimate difference in energy concentration, never any way of putting *all* the energy into one part of the system, and *none* into another, we can never turn every bit of the energy of a system into work. Some of the energy always manages to get away from us without being turned into work.

What the Second Law tells us, then, is that in the great game of the Universe, we not only cannot win, *we cannot even break even!*

Given energy at two different levels of concentration, we will note as part of the common experience of mankind that there is always a spontaneous transfer of energy from the place of higher concentration to the place of lower concentration; and never vice versa.

For instance, heat will flow, of itself, from a hot body into a cold body, but not vice versa. Water will spontaneously flow from hilltop to hill bottom but not vice versa.

We can say: "Energy will always flow spontaneously from a point of high concentration to one of low concentration."

Physicists can show that it is because this statement is true that devices will convert energy into work when there is a difference in energy concentration within the system. It is the spontaneous energy flow from high to low that produces the work.

The statement about spontaneous energy-flow is therefore another way of expressing the Second Law.

But work is never done instantaneously. It invariably occupies time. What happens during that time?

Suppose we consider a steam engine with a portion of itself that is at high heat-concentration and another portion that is at low heat-concentration. By the Second Law, the heat flows from high to low and that heat flow is turned into work. If the heat flow happened all at once and was converted into work in zero time, then we would at least get all the work out of the energy flow that we could.

But it takes time, and as time passes, some of the heat in the high concentration portion is pouring out into other parts of the Universe. Meanwhile heat from other parts of the Universe is pouring into the low-concentration portion. In other words, the hot part of the steam engine is cooling faster than you would expect just from its transfer of heat to the cold portion. The cold portion, on the other hand, is warming faster than you would think just from its receipt of heat from the hot portion.

The *difference* in temperature is dropping faster than you would expect from the work done.

Since the amount of work you can get out of any device depends upon the difference in temperature, it would seem that the quantity of energy capable of conversion into work decreases with time. The quantity of energy *not* capable of conversion into work increases with time.

A German physicist, Rudolf Clausius, pointed this out in 1865. He invented a quantity consisting of the change in heat with time, divided by temperature, and called it "entropy." He showed that entropy was a measure of the quantity of energy *not* capable of conversion into work.

In any physical change that takes place by itself the entropy always increases.

In the case of the steam engine this comes about because there is heat flow to and from the Universe. If a boulder rolls down the mountainside there is increase of entropy because of friction and air resistance. An electric current flowing from one pole of a battery to another encounters resistance from whatever it passes through and hence experiences increase in entropy.

To be sure, we can imagine ideal cases. A hot and cold area might be perfectly insulated so that heat flows only from one to the other; a rock may fall through a perfect vacuum; an electric current may flow through a perfect conductor. In all cases, there is no entropy increase.

Approximations to such ideals (a planet moving through outer space; an electric current moving through a superconducting metal) are highly special. If we consider the ordinary systems we work with, we can say: "In any energy transfer, there is an increase in entropy."

This, too, is a way of expressing the Second Law.

In fact, a good brief way of stating the First and Second Laws of Thermodynamics is: "The total energy content of the Universe is constant and the total entropy is continually increasing."

This means that although the Universe never loses any energy, less and less of that energy can be converted into work as time goes on.

The Second Law can be interpreted in terms of atomic theory, and the Scottish mathematician and physicist, James Clerk Maxwell did so in the 1860s.

Heat can be viewed, for instance, as being represented by the random movements of the separate particles (either atoms or molecules) making up some body of matter. The greater the *average* velocity of particle motion, the higher the temperature.

When two particles collide, they bounce apart and some momentum (mass multiplied by velocity) is transferred from one to the other. The transfer can take place in any fashion, but the most likely result is that the particle with more momentum will lose, and the particle with less momentum will gain. If all the particles are the same size, we can say that the faster particle will slow down after collision, the slower particle speed up. It is possible, of course, that the fast particle may just happen to bounce off faster, and the slow one slower, but it is unlikely.

(If a rich man and a poor man put all their money in a single

pile and each grabbed what he could, the chances are the rich man would end up with less money than he started and the poor man with more.)

Where more and more particles are involved, it becomes less and less likely that a large proportion of the fast particles will all bounce off slow particles and end by moving still faster.

Let us suppose there is a one-in-ten chance that a fast particle will bounce off a slow particle and become faster in the process. The chance of six fast particles *all* bouncing off faster from six slow particles will be one in ten times ten times ten times ten times ten times ten, or one in a million. The chance of ninety-six fast particles all bouncing off faster at the same time from ninety-six slow particles would be only one in a trillion-trillion-trillion-trillion trillion-trillion trillion-trillion.

Suppose you took a kettle of water containing uncounted trillions of particles and put it over a fire. It might be that more than half the hot, very fast-moving particles in the hot gases of the fire might strike the kettle and bounce off still faster-moving. In that case, the water in the kettle would get cooler while the fire would get hotter. This is possible, but the chance of its happening is so small that there is no way of writing it in ordinary figures. If you tried to write: one chance in such-and-such a number, the surface of the earth wouldn't be large enough to hold all the zeros you would have to write down for "such-and-such a number."

That is why the entropy of the Universe constantly increases—because the collisions of atoms and molecules tend always to chop off energy extremes. Wherever energy is more concentrated than usual, that concentration drops; where it is less concentrated than usual, that concentration rises.

It is also possible to think of entropy in terms of "order" and "disorder." Something is orderly when its individual parts are arranged according to some simple rule we can quickly grasp. We can then predict from each part something about the next part. The simpler the rule, the easier the prediction, and the greater the order.

Consider a deck of cards. You might have it arranged as follows: ace of spades, two of spades, three of spades, and so on, followed by hearts, clubs, and diamonds, each suit arranged from ace to king. That is very orderly, for if you show me any card (the seven of clubs, for instance), I will instantly tell you the next card (the eight of clubs).

Or you might arrange the suits in another order; or each suit might run from king down to ace; or you might have the four aces in a certain order of suits, then the four twos, then the four threes, and so on. These all represent order.

We might also arrange the cards so that they are alternately red and black without any consideration for numbers or suits. We can then still make some prediction. If I am shown the seven of clubs, I know the next card must be a red one. That is some information, but not much, so that the red and black in alternation still represents some order, but not much.

It should be obvious, though, that if you consider all the possible arrangements of the cards in a deck, the number of arrangements that allow you to make predictions about each card from the one before is a very small, a *very* small, portion of the whole.

Suppose you shuffle a deck in such a way that it can take on *any* arrangement. The chances that the arrangement will be one of the few that will allow even a small amount of prediction and will therefore have at least a small amount of order is not great. There are so many utterly disorderly arrangements possible that one of those is just about sure to be obtained.

That is why, when you shuffle cards thoroughly, you would be most astonished to find, when you were through, that the cards have ended up arranged ace of spades, two of spades, three of spades, and so on—or even red–black–red–black–red–black and so on.

Let us take another example from the world of life. When a platoon of soldiers marches by four abreast and in perfect step, that represents a high degree of order. When we see one group of four soldiers move by, we can predict exactly when the next group will pass by, how many will be in the group, whether they

will be moving their right foot or left at the moment of passing, and so on.

Other examples of order would have soldiers moving two abreast; or in single file, or one row marching and the next skipping, in alternation; and so on.

But suppose you considered all the different possible ways in which the individual soldiers of a platoon could pass by if each consulted his own tastes only and paid no attention to the others. Some might be strolling, some walking, some running, some hopping perhaps, some in this direction, some in that. The number of ways of passing *without* any perceptible order is much, much higher than the number of ways *with* order.

Consequently, if you told the soldiers of a platoon to move from one point to another at will, you would be utterly surprised if, when each did exactly as he pleased, they just all happened to move four abreast and in step. In fact, if they were already moving four abreast and in step and were suddenly told to do as they pleased, you would expect the entire platoon to break formation and become disorderly.

In short, in every possible situation you can think of, the number of ways of being disorderly is much, much, much, much greater than the number of ways of being orderly.

This is exactly comparable to the fact that the number of ways in which extremes get chopped off in the random collisions of particles is much, much, much, much greater than the number of ways in which extremes get more extreme.

Another way of stating Second Law, then, is: "The Universe is constantly getting more disorderly."

Viewed that way, we can see Second Law all about us. We have to work hard to straighten a room, but left to itself, it becomes a mess again very quickly and very easily. Even if we never enter it, it becomes dusty and musty. How difficult to maintain houses, and machinery, and our own bodies in perfect working order, how easy to let them deteriorate.

In fact, all we have to do is nothing, and everything deteriorates, collapses, breaks down, wears out, all by itself—and that is what Second Law is all about.

You can argue, of course, that the phenomenon of life may be an exception. Life on earth has steadily grown more complex, more versatile, more elaborate, more orderly, over the billions of years of the planet's existence. From no life at all, living molecules were developed, then living cells, then living conglomerates of cells, then worms, vertebrates, mammals, finally man. And in man is a three-pound brain which, as far as we know, is the most complex and orderly arrangement of matter in the Universe. How could the human brain develop out of the primeval slime? How could that vast increase in order (and therefore that vast decrease in entropy) have taken place?

The answer is it could *not* have taken place without a tremendous source of energy constantly bathing the Earth, for it is on that energy that life subsists. Remove the Sun and the human brain would not have developed—or the primeval slime, either. And in the billions of years that it took for the human brain to develop, the increase in entropy that took place in the Sun was far greater—far, *far* greater—than the decrease represented by the evolution of the brain.

But where did it all start? If the Universe is running down into utter disorder, what made it orderly to begin with? Where did the order come from that it is steadily losing? What set up the extremes that are steadily being chipped away?

Scientists are still arguing the point. Some think the Universe originally had its matter and energy all smashed together into one huge "cosmic egg"—a situation something like a tremendous deck of cards all arranged in order. The cosmic egg exploded and ever since, for billions of years, the Universe has been running down; the deck of cards is being shuffled and shuffled and shuffled.

Others think that there are some processes in the Universe that spontaneously decrease entropy; some natural process which unshuffles and re-orders the cards. We don't know what it can be, perhaps because it takes place under conditions we cannot observe and cannot duplicate in the laboratory—say,

in the center of exploding galaxies. Perhaps, in that case, as some parts of the Universe run down, others build up.

Then again, it may be that once the Universe runs down, the random collisions of particles may—after umpty ump years—just happen to bring about an at least partial unshuffling. After all, if you shuffle cards and shuffle cards and shuffle cards ceaselessly for a trillion years, you may end up with an arrangement possessing at least *some* order, just by the laws of chance.

Once that happens, the Universe begins to run down again at once. Perhaps, then, we live in a Universe that was partially unshuffled after a quadrillion years of having been run-down. We are now running down again and after the Universe is all run down, another quadrillion years or another quadrillion quadrillion years may see a section of it unshuffled once more.

Stars and galaxies will then re-form, and life may be established here and there, and finally some science writer will sit down and begin to wonder again where it all came from and where it will all end.

THE SECRET OF THE SQUID

For thousands of years, man has envied the birds their independence of the ground, their ability to soar into the sky. Yet the bird's locomotion was essentially like ours—it was the result of a push against something else.

If we walk or run, our feet push against the ground. So do the legs of a running horse, and the wheels of a moving locomotive or automobile. On the seas, the paddle or ship's propeller pushes against the water. And in the air, the wing of the bird, or the propeller of the airplane, pushes against the air.

But the air is a thin layer of gas a few miles thick, clinging to Earth's surface. What if we want to travel beyond the air, where there is *nothing* to push against. Birds and airplanes would be as helpless in space, as fish would be.

Yet there is a way out, and millions of years ago the squid discovered it. When the squid wants to dart through the water, it squirts a jet of water out behind and that makes it move forward. It is, literally, jet propelled.

So is the jet plane, of course. The jet plane sends a stream of heated gases backward and the plane proper moves forward.

It may seem that the squid's jet pushes against water and that the jet plane exhaust pushes against air, but that is not the essential part of the workings. The system of jet-in-one-direction-and-move-in-the-other would work in a vacuum, too.

We *know* it does because that's how space vehicles maneuver, but let's see *why* it does.

Imagine an object suspended in the vacuum of outer space. If there's nothing to move it, it must stay in the same place forever.

But suppose that an explosion inside the object sends part

SOURCE: "The Secret of the Squid" appeared in the New York *Times*, July 1969. Copyright © 1969 by The New York Times Company.

of it flying off in one direction. There is only one way to keep the *average* position of the object in place. The rest of the object must move in the opposite direction. As the two parts of the object continue to fly apart, the *average* position stays the same.

The faster one part is hurled in one direction, the faster the rest moves in the opposite direction. A jet plane burns fuel and sends the blazing hot exhaust gases through a narrow nozzle. Those gases must move at great velocities through the nozzle if they are to escape as quickly as they are formed, hence the plane builds up a very rapid speed, too—in the opposite direction.

Could a jet plane zoom out of the atmosphere altogether in this way? Not quite. It carries fuel only, and picks up its oxygen from the surrounding air. As the air gets thinner with height, the fuel eventually stops burning and there is no exhaust. The jet plane can gain no more speed and, as it coasts, gravitational pull brings it down into the thicker air again.

If a vehicle carried not only fuel, but also something to mix with it and make it burn (like liquid oxygen, for instance), then we would have a rocket. The rocket could keep its jet going even in outer space because it carried its own air along with itself, so to speak.

As long as the rocket jet was maintained, the vehicle would keep moving faster and faster. As soon as the jet ceased, the vehicle would coast and begin to respond to the Earth's gravitational pull (since there would now be no jet effect to counter that pull).

Like the jet plane, the rocket would proceed to drop downward and, eventually, fall to Earth. It is possible, however, for a rocket vehicle to fall without ever hitting the ground, if it is pointed in the right direction and is moving quickly enough.

Suppose a rocket vehicle is a hundred miles up and is coasting parallel to the Earth's surface. It is constantly falling, but the Earth is round and the surface of the planet is constantly curving away from the vehicle. The falling vehicle and the curving surface can move "in step" so that although the vehicle

is falling, falling, falling, it always remains a hundred miles above the curving, curving, curving surface. The vehicle is "in orbit."

In order to be in orbit, the vehicle must travel at least five miles per second. Otherwise, it doesn't move far enough, while falling, to allow the ground to curve sufficiently, and it eventually strikes the ground.

What's more, the vehicle can only do this outside the atmosphere. Inside the atmosphere, a five-mile-per-second speed would burn it up because of friction with the air.

Suppose a vehicle in orbit turns on its engines and sends out a jet of exhaust. It speeds up. After the jet is shut off, the vehicle is coasting more rapidly than it had been before. It moves farther while it falls a given amount and therefore moves away from the Earth's surface.

Now it is, in effect, climbing away from the Earth, and the Earth's gravitational pull gradually slows it. Eventually, it begins to fall back toward the Earth, speeding up as it does so.

If the vehicle continues to circle the Earth without further use of its engine, it repeats its new orbit over and over, climbing up and away from the earth, then sinking toward it again. The orbit has become a flattened curve called an ellipse.

By using the rocket engine at the proper moment and for the proper length of time, a vehicle can be put into an ellipse about the Earth that is as flat and as elongated as we wish. One side of the ellipse can stretch far out, as far as the Moon, while the other continues to hug the Earth.

By choosing the right orbit (and allowing for the fact that the Moon is itself moving and has a gravitational pull of its own) a vehicle can coast to the Moon. If the orbit turns out to be not quite perfect, an additional touch of rocket firing at the right time and for the right duration will make a mid-course adjustment that will alter the orbit and place the vehicle on target.

Actually, once it becomes possible to place a vehicle into orbit, it doesn't take much more power to reach the Moon.

The strength of the Earth's gravitational pull weakens as the

distance from the Earth increases. The greater the height a vehicle attains, the less power it takes to pull it higher still.

Suppose a vehicle is moving 7 miles per second to begin with. Earth's gravitational pull will eventually slow it to 3.5 miles per second, but by that time the vehicle will have gained such a height that Earth's gravitational pull has been cut to half its original force. Now the gravitational pull can only slow the vehicle's speed at half the original rate. It takes the vehicle as long to drop down to 1.75 miles per second as it had taken to drop down to 3.5 miles per second originally.

After every equal unit of time the vehicle's speed is cut in half (1, ½, ¼, ⅛, 1/16, 1/32, and so on) so it is never cut entirely to zero. If the vehicle leaves with a speed of 7 miles per second it need never return to earth. That speed is "escape velocity" from the Earth's surface. This means that though 5 miles per second is required just to put a vehicle into orbit, only 2 additional miles per second is needed to carry it to the Moon.

Of course, the vehicle is still in the Sun's gravitational field. If it moves past the Moon, it will therefore continue in an orbit about the Sun and become a man-made planet.

The Sun-circling vehicle might use its retro-rockets. These send out a jet of exhaust ahead of the vehicle, giving it a push in the opposite direction (i.e., backward). Naturally, the vehicle slows down and begins to fall closer toward the Sun. The orbit is a new ellipse with one end hugging the Sun, and if it is correctly chosen, the vehicle will pass close to Venus.

Or else the vehicle may make use of its rear engines to increase its speed. It will then lift away from the Sun and move into an elliptical orbit that will carry it farther from the Sun than the Earth's own orbit ever does. Along this new ellipse, the vehicle may pass close to Mars.

Suppose a vehicle in space manages to attain a speed of 26 miles per second. This is the escape velocity with respect to the Sun (at least at Earth's distance from the Sun). The vehicle can then move away from the Sun at such a speed that the Sun's gravitational field will weaken with distance too quickly to bring it back.

The vehicle can then move out of the solar system altogether and coast toward the stars.

There is only one catch. Even the nearest star is a hundred million times as far as the Moon, and with a starting speed of 26 miles a second, it would take many thousand years to reach it even if that speed could be maintained.

Even if we took off with the speed of light—186,282 miles per second—it would take 4.3 years to reach the nearest star. And faster than the speed of light nothing can go.

So reaching the stars will prove a hard problem indeed. For a while, perhaps, we had better be satisfied with the Moon.

HOW MANY INCHES IN A MILE?

How many inches are there in a mile? Quickly now.

You don't know? Of course not. Who does, except for some joker who has deliberately decided to figure it out? There are 5,280 feet in a mile (you're lucky if you remember *that*) and, of course, 12 inches to each foot. The number of inches to the mile is therefore 5,280 × 12, or 63,360.

You might wonder, though, why anyone would want to know how many inches there are in a mile. What's the difference?

None, most of the time, but this sort of difficulty comes up in problems of more immediate importance. Suppose you have a rectangular living room that is 12 feet 6 inches in one direction and 18 feet 4 inches in the other. You are going to carpet that room side to side and fore to aft, and would like to get some sort of idea of what it will cost. The carpeting is sold at a price which is so much per square yard. Therefore, you have to know the area of the room in square yards.

You are welcome to work this out for yourself right now. The necessary information you may need is that there are 12 inches to the foot and 3 feet to the yard. It may also be useful to know that there are 144 square inches to the square foot and 9 square feet to the square yard. Or perhaps you prefer to make use of the fact that there are 36 inches to the yard and 1,296 square inches to the square yard.

If you try to work out the problem three times and find three different answers at the end of the arithmetic, don't be too surprised. I worked it out in two different ways. I tried the first way twice before getting the right answer; and the second way four times! (Actually, the area of the room is almost 25½ square yards: 25.46 to be a little more exact.)

SOURCE: "How Many Inches in a Mile?" appeared in *The Saturday Evening Post*, Winter 1971. Copyright © 1971 by The Saturday Evening Post Company.

Heaven only knows how many hours your children sit hunched over their homework trying to solve problems like this! I do know, however, how many of them can still answer such problems after they have been out of school for one year. None of them!

But why is it so hard to do such a problem? After all, to work out the area of a rectangle we need only multiply the lengths of adjacent sides. A rectangle that is 12 feet by 18 feet is 12×18 or 216 square feet in area.

The trouble seems to be that what is easy where only feet are involved becomes difficult when inches and yards are dragged in as well because one unit goes into another an inconvenient number of times. Why are there 3 feet to the yard? Why not 2, or 4? Why 12 inches to the foot? Why 5,280 feet to the mile?

The answer is that each measure arose independently in the dim, dim past, each being based on the only handy measuring system available to all human beings, however primitive—the human body itself.

The end joint of the adult thumb is about an inch long and can be used to measure off the width of a sheet of paper. The length of the foot is about a foot (of course!) and can be used to mark off, heel to toe, the length of a room. The distance from the tip of the fingers of an arm, outstretched sideways, to the tip of the nose is about a yard, and this can be used to measure off lengths of cloth from a bolt.

This is convenient, but each person's measurement is slightly different from that of the next. To get a bargain you would have to buy cloth from a merchant with a long arm—and he will send out a short-armed assistant to do the measuring.

For that reason, standard measures are adopted; a yard rule or a foot rule is constructed that is to be the same everywhere. It is convenient to have such a rule divided into smaller measures, so that a yard rule is divided into feet and inches. Naturally, the different units don't fit quite evenly to begin with, but they can be made even. There are about twelve thumb end

lengths in the length of a foot, and about three foot lengths in the length from fingertip to nose. Make it exact for convenience and you end with 12 inches to the foot and 3 feet to the yard.

The Romans based a longer unit on the marching of their legions. They measured distances as so many thousands of the paces stepped off by the swinging strides of the Roman soldiers. They called a thousand paces "mulia passuum" and in English, this became "mile."

The Roman thousand-paced mile is a little over 5,000 foot lengths. Why not make it 5,000 feet to the mile? The English, however, had a smaller unit called the "furlong," which was the length of a conveniently sized furrow ("furrow-long") formed in plowing. The furlong is 220 yards. A 5,000-foot mile would be roughly 7½ furlongs long, and it seemed more convenient to make the mile just 8 furlongs long, or 5,280 feet, or 1,760 yards.

The same sort of hit-and-miss jamming together of different units was done in the case of other kinds of measures.

In measuring the volume of liquids such as water, wine, or milk, there are 4 fluid ounces to the gill, 4 gills to the liquid pint; 2 liquid pints to the liquid quart, and 4 liquid quarts to the gallon. (There are also 9 gallons to the firkin and 7 firkins to the hogshead.) I wonder if anyone ever remembers for sure whether it is 4 pints to the quart and 2 quarts to the gallon, or 2 pints to the quart and 4 quarts to the gallon?

Of course, if you are measuring non-liquid materials, such as grain, flour, or vegetables, there are 2 dry pints to the dry quart, 8 dry quarts to the peck, and 4 pecks to the bushel.

Are you curious as to why I specify liquid pints and dry pints? Well, they're different. A dry pint is about 1⅓ liquid pints, so that 6 pints of flour is equal in quantity to 7 pints of milk. The same discrepancy holds for liquid quarts and dry quarts.

At least that is the way the Americans do it. The British make use of the same pints and quarts for both liquid and solid. Their pints and quarts, however, are different from both our varieties. The British "Imperial Gallon" is 1⅕ American gallons, as you will find when you buy gasoline in Canada.

As far as weight is concerned, there are 16 ounces to the pound and 2,000 pounds to the ton (or 2,240 pounds to the "long ton"). To this, the British add 14 pounds to the stone and are always saying that someone weighs 12 stone when they mean 168 pounds.

Of course, this is "avoirdupois weight," which you use most of the time. In measuring gold, gems, or drugs, you use "Troy weight," in which there are only 12 ounces to the pound—and the Troy ounce is not the same as the avoirdupois ounce. The Troy ounce is equal to about $1\frac{1}{10}$ avoirdupois ounces.

It is possible to go on and on and talk about acres and carats and cubic feet and drams—but surely you get the point. The interrelationship of the common units of measure is a jungle through which no one can possibly find his way.

Is there any way of switching to sanity? Yes! All the rest of the world has made that switch. In almost every other nation in the world, schoolchildren can learn all they have to know about units of measurement in a day, and they can remember it for the rest of their lives.

Sanity is the metric system!

The metric system was devised in France in 1795. At that time, France had a system of measures as insanely complex as did England and the baby nation of the United States.—So did every other nation on Earth, no two alike, save in their utter lack of logic. Often measures varied from section to section within a nation.

In 1795, however, France was in the midst of revolution and a new start seemed advisable. They decided to invent a system of measurements with simply and logically related units.

They did so, beginning with a "meter," a unit that, originally, represented a ten millionth of the distance from the Equator to the North Pole and that comes out to be equal to just a little over a yard in our common units. The French then divided the meter into ten smaller units, each smaller unit into ten still smaller ones, and so on. They also built up the meter into larger units by tens. To summarize in table form:

1 kilometer = 10 hectometers
1 hectometer = 10 dekameters
1 dekameter = 10 meters
1 meter = 10 decimeters
1 decimeter = 10 centimeters
1 centimeter = 10 millimeters

The names may seem strange at first, but once they are memorized in the correct order, our work is almost done.

Converting one into another is simple. How many centimeters are there in a kilometer? 100,000. How many meters in a hectometer? 100. Once you have memorized the order, it's just a matter of multiplying tens.

In fact, it's even easier than that. Since the decimal system is based on tens also, the metric system can be manipulated by shifting decimal points. A length equal to 27 decimeters is also equal to 2.7 meters, to 270 centimeters, and to 0.27 dekameters.

Suppose, for instance, you have a rectangular room which is 32 decimeters 4 centimeters long and 49 decimeters 6 centimeters wide, and you want to carpet it completely at a price of so much a square meter. That sounds like our earlier problem in yards, feet, and inches, but—

Anyone using the metric system sees at once that 32 decimeters 4 centimeters is equal to 32.4 decimeters or 3.24 meters; and that 49 decimeters 6 centimeters is equal to 49.6 decimeters or 4.96 meters. The area is 3.24×4.96, or just about 16.07 square meters. You have that one nasty multiplication to make and no divisions. All the rest is taking care of the decimal point.

Furthermore, other types of measurements are tied in with the meter. Consider a cubic decimeter; that is, a cube with each side one decimeter long. Such a cube, if empty, will hold one "liter" of material. The liter is the basic unit of volume in the metric system. It can be divided and multiplied by tens just as the meter is and *with the same prefixes*. Since a millimeter is a tenth of a centimeter and a thousandth of a meter, you can be sure that a milliliter is a tenth of a centiliter and a thou-

sandth of a liter. Again all switches can be made by shifting decimal points.

Next, a milliliter of water weighs one "gram." That is the unit of weight in the metric system. A kilogram is 1,000 grams and a milligram is 1/1000 gram. You already know that, and can work out all the rest yourself with no further information from [illegible]

In actual practice, things are still simpler. In units of length, one rarely runs into the hectometer, dekameter, or decimeter. About nine tenths of the time, it is sufficient to remember that 1 kilometer = 1,000 meters; 1 meter = 100 centimeters; 1 centimeter = 10 millimeters.

In volume, liter and milliliter are the only units commonly encountered, so 1 liter = 1,000 milliliters is almost all you need to know. As for weight: 1 kilogram = 1,000 grams; and 1 gram = 1,000 milligrams. That gives you the story.

There's more to it, of course, but with what I have told you, it would be possible to make use of the metric system for almost every run-of-the-mill purpose. A child can learn in a day and memorize for life more about the metric system than you or I have been able to learn and retain about our common system in a lifetime.

The usefulness of the metric system is such that it spread over all the world quite rapidly. Nation after nation adopted the new French system. Only the English-speaking nations held out into the mid-twentieth century. Now even they are falling into line and the only holdout of any consequence among all the nations of the world is the United States of America. The next largest nation that still resists the metric system is, I believe, the African nation of Liberia.

What does this mean?

For one thing, *only* American children will waste incredible numbers of hours trying to ram into their heads an unlearnable system, when they might be learning something useful instead. Only American children will have this additional reason for learning to hate school. All other schoolchildren, including Rus-

sians and Chinese, dismiss the measurement system in a day of explanation and a week of practice

What else? All scientists everywhere, *even in the United States*, use the metric system *exclusively* in their scientific labors Everywhere else, scientists use the metric system in daily life and learn it as children In the United States, scientists learn the metric system only late in life and have to keep on using the common system also It means that American scientists are never quite as much at home with their basic language of measurement as are all other scientists.

What else? Only American industry makes use of the inches and pounds The rest of the world is on the metric system A double standard must therefore be used in international trade, with ourselves inevitably on the losing side.

The United States *must* accept the metric system sooner or later, then. It is not too late now Would that it had been done long ago in the infancy of the republic, but better now than later

Of course, the in-between generation, the one which must abandon the common units and adopt the metric ones, will be a little uncomfortable, but that can't be helped. And it can be lived with—

A mile is equal to 1⅔ kilometers A yard is equal to ⅞ of a meter. An inch is equal to 2½ centimeters. Those equivalences aren't exact, but they are sufficient for everyday purposes and it is not so brutal to memorize them If you travel 2½ miles to get to work, that becomes 4 kilometers If your speedometer reads 60 miles an hour, that is a thrilling 96 kilometers an hour. If you are 6 feet tall (72 inches) that is the same as 180 centimeters of height or 1 8 meters. If your girl's measurements are a lovely 34, 24, 34 in inches, they become an astounding 85, 60, 85 in centimeters.

As for the liter, that is equal to 1⅛ liquid quarts. A liter of milk will seem just the same size as a quart of milk. You'll hardly notice the difference.

The kilogram is equal to about 2⅕ pounds. Put it another way—a pound is equal to about 450 grams and 3 ounces is equal

to about 85 grams. If you weigh 170 pounds, that is about 76,500 grams or (move the decimal point three places to the left since there are 1,000 grams in a kilogram) 76.5 kilograms. Your 16 pound turkey will weigh 7.2 kilograms, and your quarter pound of butter will be a little over 110 grams.

This is an inconvenience, perhaps, but you will get used to it; butter will begin to be sold in even 100-gram lots soon enough; you will forget feet and pounds after a while and use meters and grams instead without having to translate in your mind.

And even if you remain annoyed, your children will be less annoyed and your grandchildren will bless you (as you would be blessing your grandparents if they had had the gumption to abandon insanity and go through a little trouble for *your* sake).

Nor will everything change, you understand. Working in the kitchen will scarcely be affected. Half a cup of sugar will remain half a cup though metric systems come and common systems go, and while you have your fingers, a pinch of salt will remain a pinch of salt and nothing else.

Oh, and by the way, before I sign off: How many inches were there in a mile? No, don't look back. Forgotten again, have you? Well, how many centimeters in a kilometer?

This article is especially dear to me because I was supposed to be taking it easy for two weeks and when nobody was looking, I cheated and wrote it.

BEYOND THE ULTIMATE

Until less than two hundred years ago, man could go on land no faster than a racing horse, and on sea no faster than the wind could push a ship. Through the air, he could not go at all, that was for birds and dreams.

Then came the age of vapors. Hydrogen, lightest of the gases, lifted balloons into the air and men were soon floating mountain high. Steam, boiling forcibly out of water, turned mighty wheels and sent ships racing upwind and upstream, and locomotives speeding over steel rails. Gasoline vapors, combining with air in tiny explosions within engines, made possible the automobile and the airplane. Finally, gaseous exhausts, blowing furiously downward, lifted enormous rocket ships majestically through all the miles of atmosphere and out into space itself.

In less than two centuries, man reached the ultimate; the very limit of earthly speed. An astronaut circling the earth in ninety minutes is traveling at nearly five miles a second and that is as fast as he can profitably go. At this speed, Earth's gravitational pull inward is just balanced by the centrifugal effect pushing him outward and he remains at a fairly constant height above the Earth's surface.

Were an astronaut to insist on increasing his speed by firing his rear rockets, the centrifugal effect would strengthen and overpower the gravitational pull. The rocket ship would move away from Earth just as an automobile would go skidding off the road if it took a corner too quickly.

Of course, an astronaut might not only fire his rear rockets but might also fire auxiliary side rockets to push him downwards toward the Earth. He would then take the corner, so to

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speak, at an unusually high speed while a mighty rocket-powered force pushed inward and kept him from "skidding off the road."

In doing this, however, the energy expended would far outweigh the time gained. Moreover, the astronaut would feel an outward-directed force upon himself that would mount rapidly as speed increased and would quickly become unendurable.

No, if we are to insist on traveling at more than this "ultimate" speed of five miles a second, there's only one place to go and that is away from Earth altogether.

This departure from Earth has already been accomplished. By 1969, manned spaceships had reached the Moon; unmanned spaceships had reached the vicinity of Mars and Venus.

Actually, once we attain a speed of more than seven miles a second, we can move on indefinitely against the pull of Earth's gravity (which, after all, gets weaker and weaker as we move farther away). At such speeds, we can coast as far as we like, without the expenditure of further fuel and (provided we avoid being trapped in the gravitational field of any astronomical object in between) we can reach any point in the Universe *given sufficient time.*

But that "sufficient time" is long indeed. Planetary distances beyond our immediate neighbor-worlds are huge and even seven miles a second is slow. It would take us over a year to move into Jupiter's orbit at such a speed and over a decade to move into Pluto's orbit.

If we accelerated to a more rapid speed before moving into the coasting stage, the time of journey is cut down, but there is a limit to what we can do in that direction. Acceleration costs fuel, tremendous quantities of it, and if we expect to accelerate to really high velocities with chemical rockets of the types used today to reach the Moon, the quantity of fuel required would make a spaceship prohibitively large.

The chemical rocket is not the last word, of course. Controlled nuclear explosions would drive exhaust gases backward at far greater velocities than is the case with ordinary chemi-

cal combustion. The greater energy of the exhaust would allow longer accelerations and greater final velocities per mass of fuel. A nuclear-powered spaceship could be reasonably compact and yet carry enough fuel to reach the outer solar system.

Even with nuclear power the time of journey could not be cut indefinitely. Acceleration must be held below a certain limit for the human body could not tolerate more, and in a journey of a certain length, only a certain velocity can be attained. It is probable that as long as we depend on any reaction motor, whether chemical or nuclear, exploration of the outer solar system will involve voyages that will endure for years.

A voyage of several years is perhaps within human achievement if the prize is large enough, but even such voyages will carry men only through our own solar system. What about the regions that lie beyond?

Outside our solar system is a whole Galaxy of stars, 135 *billion* of them, most of them, perhaps, with planetary systems of their own. Can we reach these other stars and their possibly attendant families of planets?

Unfortunately, even the nearest star is 25 trillion miles away, and such a distance is a most effective insulator. Coasting along at seven miles a second, it would take a spaceship one hundred thousand years to reach that nearest star. It would take two billion years for it to reach the other end of our Galaxy and forty billion years to reach the next large galaxy.

The solar system is a tiny island in an unimaginably large and unimaginably empty ocean of space. To cross the gap between one tiny planetary system and another is a proposition altogether different from travel within the solar system itself.

We might, of course, simply accept the time element.

Suppose we used efficient nuclear rockets and carried enough fuel to build up a speed of 700 miles a second. It would still take a thousand years or so to reach the nearest star and another thousand years to return.

To handle that, we might build a ship large enough to serve as a miniature world: a ship that would recycle its water and

air, supply its own energy from fusion reactors, grow its own food, provide comfort for its own people. On that ship, generations of men would, each in its turn, be born, live, and die.

Eventually, the thirtieth generation would reach the vicinity of the nearest star, with (who knows?) Earth forgotten, the original purpose of the ship a dim and legendary memory. Even if records had been maintained, the thirtieth generation might have no interest in Earth any longer but would continue in the only life they knew and cared for, journeying on forever in the private little Universe that was their home.

For that matter, would the people of Earth be able to build up enthusiasm for the outfitting of ship-Universes to be launched in various directions at various target stars with no return possible for millennia? They have engaged in long range projects, yes (the medieval cathedrals, for instance), but only when progress, however slow, was at least visible.

Alternatively, it might be possible to freeze the ship's crew for indefinite periods, with automated machinery designed to thaw and rouse them when the destination is near at hand. (No method is now known that will serve to freeze human beings into true suspended animation with all physiological functions entirely unimpaired, but we may suppose that someday a method for doing this will be discovered.)

Through freezing, the *orginal* crew might reach the destination even though thousands of years had passed. They would remember their purpose and, presumably, be highly motivated to return to Earth. But on Earth, those thousands of years would still have passed and the lack of enthusiasm for a project in which neither end nor progress was visible in one's own lifetime would still be a factor.

Great time lapses must be eliminated, then. Higher speeds must be attained; much higher speeds.

One way in which this can be done is by using an ion drive. Instead of making use of gases, heated by either chemical or nuclear reactions, and emerging from the rear in huge masses at several miles a second, we can send individual ions (that is,

electrically charged atom fragments) out the rear These ions would have very little mass but they could be made to move at speeds of several tens of thousands of miles per second

An ion drive would produce very small accelerations thanks to the tiny masses involved, but precisely because so little mass is used up, there would be enough fuel to continue that acceleration for years if necessary. Speeds would build up to a hundred thousand miles per second or more. Now the nearer stars can be reached in a single man's *unfrozen* lifetime, and, what's more, they could be reached in the lifetime of men on Earth. Dozens of stars might be reached in fifty years or less.

But these stars are only those in our immediate neighborhood What about more distant stars? The many billions of them?

Well, if one goes faster and faster (according to Einstein's Special Theory of Relativity) the passage of time proceeds more and more slowly for the speeder For speeds over 160,000 miles per second, this slowing of time is considerable and for speeds over 180,000 miles per second, it is enormous (see the earlier article, *Time*).

Astronauts moving through space at better than 180,000 miles per second might, in what seems to them to be merely twenty-five years, reach the other end of the Galaxy. (That is, in their *slowed* time. On Earth, with time moving at its usual velocity, the time lapse would seem much, much greater.)

There is, in fact, an ultimate speed—186,282 miles per second. This is the speed of light in a vacuum. At that speed, time slows to an utter halt.

And this raises a thought It is absolutely necessary to transfer a massive object itself through space? Can we perhaps merely transfer the description of the mass As a familiar analogy, we need not send a document across a continent; we merely reduce it to a succession of light and dark dots that adequately characterize the document. These are converted into a fluctuating electric current, and this current sends its message *at the speed of light*, across the continent, to be

reassembled at the receiving point into a facsimile document.

Is it possible to reduce matter to a fluctuating beam of photons (the tiny "particles" that make up light and other forms of radiant energy) that would completely describe that sample of matter? This beam could then be sent across space for reconversion to a duplicate of that matter at some receiving point.

Could a photon beam of this sort be made to represent a human body, or a complete spaceship with its cargo of human bodies? I would hate to predict that it could, for it would be an accomplishment of unimaginable complexity—but I would have said this in 1800 concerning a flight to the Moon.

If "mass-transference" becomes possible, then an astronaut could conceivably be transported *anywhere* in the Universe at the speed of light. To that astronaut, *no time at all* would seem to have elapsed from conversion to reconversion.

However, though an astronaut might travel at nearly the speed of light and experience little time lapse, or actually at the speed of light and experience no time lapse at all, time would still proceed in its ordinary fashion on Earth. The photon beam that is an astronaut would still take 4.3 years, Earth time, to reach the nearest star and 100,000 years to traverse the Galaxy from end to end.

Nothing so far described would make it possible to do more than reach our neighborhood stars, the fifty closest perhaps, within the lifetime of a stay at home on Earth; and it would be only these neighborhood journeys that Earth might be willing to support.

Well then, could a spaceship travel at speeds greater than that of light? Until recently, the answer would have been a flat negative. The speed of light in a vacuum is an ultimate velocity according to Einstein's Special Theory of Relativity and no one today doubts the validity of that theory.

But in the 1960s, a vision that stretched beyond the ultimate was presented. It was pointed out that if the speed of light was viewed as an impenetrable limiting wall, it might be argued that a wall has two sides. On the other side of the wall might

exist a whole universe of particles that could only move *faster* than the speed of light and could never slow down below that speed and yet fulfill all the requirements of Einstein's theory.

These super-fast particles are called "tachyons" from a Greek word meaning "swift."

Such tachyons would have odd properties indeed, and the one that concerns us at the moment is this: The *more energy* you pump into a tachyon the *slower* it would go, until at very large energies it would slow down almost to the speed of light. The *less energy* present in a tachyon the *faster* it would go until at very low energies it would travel millions of light-years per second.

Tachyons would not interact with ordinary particles and could not be detected through collisions. Since they move so rapidly, they are in our vicinity and, therefore, capable of being detected, for only a tiny fraction of a second. Nevertheless, theory requires a passing tachyon to produce a tiny, but perhaps detectable, flash of light as it passes. Physicists have tried to detect those flashes and so far, they have failed.

That, however, doesn't really matter. Even if tachyons aren't actually detected, they may nevertheless exist, and perhaps that means that though none are to be found at the moment, some can be created—if we only knew how.

Well, we have already imagined the conversion of matter (and whole men-packed spaceships) into a stream of photons that would carry all the information of the matter precisely, and that could be reconverted into an exact duplicate of the original at a far distant point.

Having gone that hog-wild, why not go one more step and suppose that matter could be turned into a stream of tachyons, rather than photons?

Such a beam of tachyons, if sufficiently low in energy, would move so rapidly that it might reach the vicinity of the nearest star, say in five seconds. That five-second time lapse would hold not only for the astronauts themselves but also for the stay-at-home Earthmen. The Galaxy might be spanned in a minute, the most distant outer galaxies reached in a week.

To such a beam of tachyons, the whole enormous Universe would be but an insignificant speck.

It might also be possible to use modulated beams of tachyons to carry messages from one far distant star to another. In this way, both transportation and communication might become possible over all distances, however great, and, what's more, with virtually no time lapse.

This means that it is no longer utterly inconceivable that the day (a far distant one, perhaps) might come when the ultimate is surpassed and all the vast Universe becomes man's neighborhood.

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